1
CHAPTER 4

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2
COASTAL WETLANDS

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124 # 4.1   INTRODUCTION

125 This chapter provides guidance on estimating and reporting anthropogenic greenhouse gas (GHG) emissions and
126 removals from managed coastal wetlands.

127 Coastal wetlands are defined here as organic and mineral soils vegetated by vascular plants that are covered or
128 saturated for all or part of the year by tidal freshwater or salt water (>0.5ppt) at or near the coast. The boundary
129 of coastal wetlands is recognized as the landward extent of tidal inundation and extending seaward to the
130 maximum depth of vascular plant vegetation with 95% of seagrass meadows being found shallower than 40
131 meters water depth (Duarte 1991).This description is derived from recent definitions in a specialized treatise on
132 coastal wetlands (Perillo et al. 2009) and from a global treatise on all wetlands (Aber et al. 2012). This definition
133 and this chapter thus refer specifically to tidal freshwater and salt marshes, seagrass meadows, and mangrove
134 forests. All vegetation types occur on both mineral and organic soils. The guidance in this chapter applies to all
135 managed coastal wetlands that can occur in any IPCC land category and addresses all IPCC pools (Table 4.1).

136 Supplementary guidance (Table 4.1) is structured to address greenhouse gas emissions and removals for Land
137 Remaining in a Land-use category (Section 4.2), Land Converted to another Land-use category in which the land
138 that is converted is a coastal wetland (Section 4.3), and Conversion to a Land-Use category that includes coastal
139 wetlands (Section 4.4) regardless of how it is classified. Management activities that have significant impacts on
140 national level CO_2 emissions and removals vary depending on country circumstances. This chapter provides
141 guidance on management activities that will not be relevant for all countries but is meant to be inclusive of those
142 activities that are common in managed coastal wetlands. The guidance is thus structured to aid the inventory
143 compiler to identify areas of managed coastal wetlands and report on management activities that impact
144 greenhouse gas emissions and removals. It should be noted also that depending on how managed coastal
145 wetlands are classified, the effect of the management activity may or may not result in a land-use change. This is
146 an especially important consideration for the guidance provided in this chapter. Inventory compilers should also
147 be mindful that, *significant* greenhouse gas emissions and removals can result in an IPCC Wetlands land
148 category that is *key* regardless of whether a land-use conversion has occurred (in reference to *significant* and *key*,
149 see Chapter 4, Volume 1 of the *2006 IPCC Guidelines*). As such, to ensure complete coverage, this guidance
150 enables the use of the IPCC Land category reporting system. Methodological assumptions and issues more
151 specific to the three categories are discussed in the corresponding sections of this chapter. Readers are referred to
152 Volume 4 of the *2006 IPCC Guidelines* for many of the basic equations to estimate greenhouse gas emissions,
153 but methodological assumptions and other deviations are highlighted throughout the text, especially with regard
154 to new activities including aquaculture and salt production where new methodological guidance is provided. The
155 Decision Tree guides the inventory compiler to the appropriate Tier level estimation methodology as is followed
156 in the *2006 IPCC Guidelines* (Figure 4.1).

TABLE 4.1 MANAGEMENT ACTIVITIES IN COASTAL WETLAND ECOSYSTEMS RELATED TO LAND-USE CATEGORY AND CHAPTER SECTION		
LAND REMAINING IN A LAND-USE CATEGORY: Section 4.2 (This section covers management activities that occur in coastal wetland ecosystems and that may or may not result in a conversion to another land-use category.)		
Activity	**Ecosystems Affected**	**Subtype**
Aquaculture (AQ)	Mangrove forests, Tidal marshes	Fish, shrimp ponds
	Seagrass meadows	Fish cages, pens
Salt Production (SP)	Mangrove forests, Tidal marshes	
	Seagrass meadows	NA[1]
Extraction (EXT)	Mangrove forests, Tidal marshes, Seagrass meadows	Dredging; Port, harbour and marina construction; filling
Harvesting of Aquatic Resources (HARV)	Mangrove forests	Wood, Charcoal, Land clearing
	Tidal marshes	Grazing (cattle, sheep)
	Seagrass meadows	Fish, Shellfish

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Nutrient Enrichment (NUTR)	Mangrove forests, Tidal marshes, Seagrass meadows	
Hydrologic/Sediment Diversion (DIV)	Mangrove forests, Tidal marshes	Impoundments, barriers, oil and gas extraction - resulting in soil elevation loss
	Seagrass meadows	NA
Drainage (DR)	Mangrove forests, Tidal marshes	Agriculture, forestry, mosquito control
	Seagrass meadows	NA
Restoration (RES) and Creation (CRE)	Mangrove forests, Tidal marshes	Reestablishment of vegetation following hydrologic or sediment modifications
	Seagrass meadows	Reestablishment of vegetation following water quality improvements
Other Activities	Mangrove forests, Tidal marshes	Recreation (hunting), fire management
	Seagrass meadows	Recreation (anchoring, mooring, boating), salt production

CONVERSION FROM A LAND-USE CATEGORY THAT INCLUDES COASTAL WETLANDS Section 4.3 (This section covers the conversion of a Land-use category that includes coastal wetlands to another Land-use Category, primarily including (1) drainage in which the soil water table is lowered for conversion to Cropland or Grassland or (2) excavation of soil resulting in conversion to Settlement.
CONVERSION TO A LAND-USE CATEGORY THAT INCLUDES COASTAL WETLANDS Section 4.4 (This section covers restoration and creation of coastal wetland ecosystems in which a Land-use conversion occurs.

NA =not applicable; [1]no available Tier 1 guidance

157 # WHAT IS NOT COVERED IN THIS CHAPTER

158 For constructed wetlands that occur in coastal zones that are modified to receive and treat waste water, refer to
159 Chapter 6 (this Supplement). Chapter 6 also covers semi-natural treatment wetlands which are natural wetlands
160 where wastewater has been directed for treatment but the wetland is otherwise unmodified. With reference to
161 nutrient enrichment as an activity in coastal wetlands, this chapter on coastal wetlands covers CO_2, CH_4 and N_2O
162 emissions from aquaculture and effluent derived from aquaculture as well as CH_4 emissions from untreated,
163 uncollected agricultural runoff and leaching resulting from direct nutrient application to terrestrial soils. Nutrient
164 enrichment effects on CO_2 emissions from this type of agricultural run-off affecting mangroves and tidal
165 marshes is not covered as there is inadequate information to provide emission factors for all pools and risk of
166 double-counting across pools. Direct and indirect N_2O emissions from soils associated with N applied to
167 terrestrial soils (direct and indirect) are covered in Chapter 11, Volume 4 of the *2006 IPCC Guidelines*. This
168 Chapter only covers N_2O emissions during stocking of aquaculture and as a result of effluent from aquaculture in
169 the coastal wetland. This chapter covers emissions from these lands, but excludes carbon losses or gains via tidal
170 exchange (see Section 4.6).

171 # SPECIAL CONSIDERATIONS FOR THE APPLICATION OF THE WETLANDS
172 # SUPPLEMENT GUIDANCE FOR COASTAL WETLANDS

173 Special considerations for the application of the Wetlands Supplement guidance for coastal wetlands include an
174 understanding of: A) how to identify coastal wetlands, B) treatment of managed lands in coastal wetlands, C)
175 identification of coastal ecosystems, D) soil type, and other generally applied assumption for soils.

176 ## A. Identification of coastal wetlands

177   **Figure 4.1 Decision tree to estimate greenhouse gas emissions and removals due to management**
178   **activities in coastal wetlands.**

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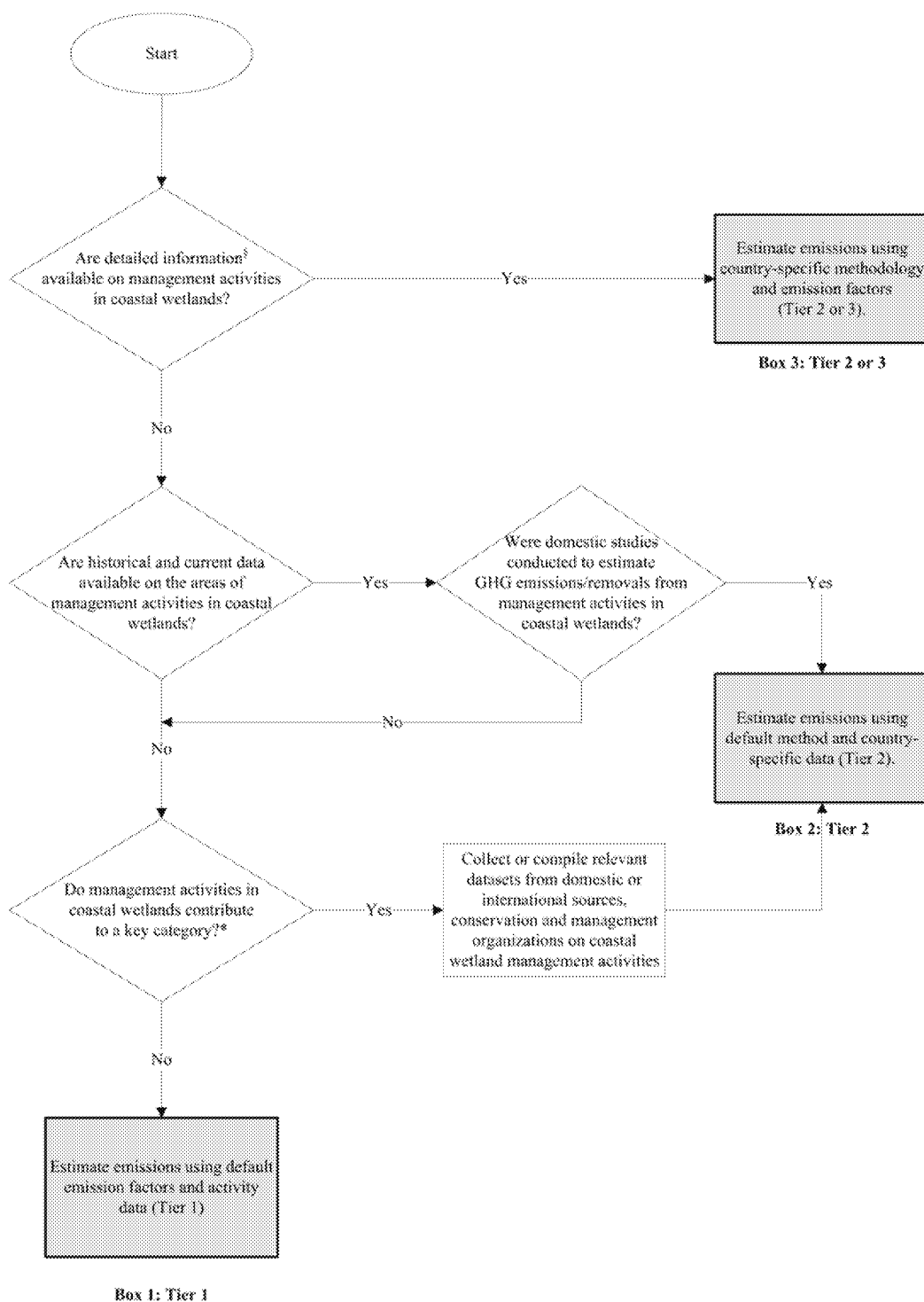
180   *A key source/sink category is defined in Chapter 4, Volume 1 of the *2006 IPCC Guidelines*, "as one that is prioritised within the national
181   inventory system because its estimate has a significant influence on a country's total inventory of greenhouse gases in terms of the absolute
182   level, the trend, or the uncertainty in emissions and removals". The *2006 IPCC Guidelines* recommend that the key category analysis is
183   performed at the level of land remaining in or converted to a land-use category. If CO_2, CH_4 or N_2O emissions/removals from coastal
184   wetlands are subcategories to a key category, these subcategories should be considered as significant if they individually accounts for 25-30%
185   of emissions/removals for the overall key category (see Figures 1.2 and 1.3 in Chapter 1, Volume 4 of the 2006 IPCC Guidelines.

186   The first priority for inventory compilers is to determine if the managed wetlands under consideration conform
187   to the definition and boundary of coastal wetlands that have been described. In many regions, these boundaries
188   have been mapped using aerial photographs or remotely sensed data, and confirmed by field inspections, and in
189   the form of freely available data (refer to respective sections on Activity Data and Annex 4.2). Wetlands are by
190   definition lands with minimal slope and vegetated by species adapted to temporary, regular or permanent
191   coverage by tidal freshwater or salt water (>0.5ppt) and saturated soil conditions. Many plant species are salt
192   tolerant or salt resistant and may be adapted to grow fully submerged. Thus, wetlands can be identified by the
193   presence of these specialized plant species or by soil characteristics that reflect flooded conditions (e.g., organic
194   carbon content >12% or in mineral soils the presence of mottling).

195   B. Treatment of managed lands in coastal wetlands

196   The second priority for inventory compilers is to apply the concept of managed land in order to focus time and
197   resources and report on management activities that impact anthropogenic emissions and removals of greenhouse
198   gases at the national level. The activities that will result in the largest greenhouse gas emissions or removals are
199   those that: 1) include removal and oxidation of soils (eg. aquaculture, salt production, extraction, drainage), 2)
200   have both initial and sustained effects (eg. aquaculture, salt production, restoration) or 3) affect more than one
201   pool. Additionally, for example, those activities which result in removal of forest biomass would have a larger
202   impact than those that result in removal of tidal marsh biomass. So, the land area in which the activity occurs
203   (coastal wetland ecosystem type) is also an important consideration in documentation and reporting of
204   management activity impacts. Furthermore, IPCC *good practice* guidance requires documentation and reporting
205   of all IPCC pools.

206   C. Identification of ecosystem types

207   A further consideration when applying the guidance in this chapter is the ecosystem type that is the subject of the
208   management activity. Just as all management activities will not occur in all countries, not all management
209   activities occur in all ecosystem types nor will all coastal wetland ecosystem types be considered managed.
210   Coastal wetlands can occur in any IPCC land-use category regardless of how the land is classified (see examples
211   Box 4.1). While countries should follow their own national definitions of coastal wetland ecosystem types, some
212   general features that may help in consistent identification can be found throughout this guidance.

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213 **BOX 4.1. THE FOLLOWING REPRESENT EXAMPLES OF DIFFERENT MANAGEMENT PRACTICE THAT DO OR DO NOT**
214 **RESULT IN A CHANGE OF A LAND-USE CATEGORY.**

215 *For Land remaining in a land-use category:*

216 When areas of fish pens constructed within seagrass meadows are classified as Wetlands.

217 When tidal marshes or mangrove forests are classified as Wetlands and exploited for aquaculture or
218 drained for agriculture that is also classified as Wetlands.

219 When selective harvesting or forest clearing occurs in mangrove forests that are classified as Wetlands to
220 provide wood for fuel, charcoal or construction.

221 *For Conversion from a land-use category that includes coastal wetlands:*

222 When areas of fish pens constructed within seagrass meadows are classified as Settlements or Other Land.

223 When tidal marshes or mangrove forests are classified as Wetlands and exploited for aquaculture or
224 drained for agriculture with that land area classified as Cropland. If the soils are organic and permanently
225 drained for Cropland uses, refer to guidance in Chapter 2 of this Supplement. If the soils are mineral and
226 permanently drained for Cropland uses, refer to guidance in Chapter 5 of the *2006 IPCC Guidelines*.

227 When mangrove forests classified as Forest Land are deforested, drained and maintained as grazing land
228 and subsequently classified as Grassland.

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229   D. Identification of soil types

230   A unique aspect of this chapter in the Supplement is that coastal wetland ecosystems can occur with either
231   mineral or organic soils. For some management activities, soils may be aggregated and the same emission factor
232   applied regardless of the soil type (i.e. drainage, restoration and nutrient enrichment). However, emission factors
233   do vary based on ecosystem types and Tier 1 methods disaggregate ecosystem types on this basis. For other
234   management activities, emission factors are disaggregated by soil type (i.e. aquaculture, salt production). This

235   refinement results from the differing methodologies applied in these cases.   Once management activities are
236   identified, the inventory compiler should consider whether soil type must be determined. Thus, the fourth
237   priority for inventory compilers is to distinguish organic from mineral soils in coastal wetlands once
238   management activities and ecosystem types have been identified for Tier 1 estimation in the absence of soil map
239   data. There are two assumptions that can be applied at Tier 1:

240   (i)   Assumption 1: Soils which are or become colonised by seagrass meadows are assumed to be mineral.

241   (ii)   Assumption 2: Soils in or at the mouth of estuaries or adjacent to any river characterised by a large
242   and/or mountainous catchment and high flow are assumed to be mineral soils. For all other mangrove
243   forests (sometimes termed oceanic mangroves) and tidal marshes the soils are assumed to be organic.
244   See Durr et al. 2011for additional national level guidance.

245   4.1.1   Land remaining in a land-use category

246   The known management activities that occur in coastal wetlands and that may not result in their conversion to
247   another IPCC land-use category depending on how those lands are classified are aquaculture, salt production,
248   extraction, harvesting of aquatic resources, nutrient enrichment, hydrologic/sediment diversion, drainage,
249   restoration/creation and other activities (Table 4.1). In the following sub-section, these activities and how they
250   affect the coastal wetlands they primarily impact are described. All methodological guidance is found in section
251   4.2. When management activities do not result in a land-use category conversion, follow guidance in section 4.2.
252   When a land-use category conversion is involved, refer to guidance in sections 4.3 and 4.4 which direct the
253   inventory compiler to the appropriate methodological guidance.

254   **Aquaculture (shrimp ponds, fish ponds, fish cages)**

255   There exists a range of aquaculture practices, but the most important, and ones that commonly occur in coastal
256   wetlands, are fish farming and shrimp ponds (World Bank 2006).

257   *Mangrove Forests and Tidal Marshes.* Shrimp and fish ponds in these settings are identified through three
258   phases: construction, use and abandonment. In the first phase they are constructed by clearing vegetation,
259   levelling, followed by excavation of surface soils to build containing berms within which water is held. During
260   construction, carbon from the cleared biomass and excavated soils is lost from storage and subsequently oxidized
261   (World Bank 2006). While in use (second phase), ponds are stocked with fish and shrimp, and soils underlying
262   ponds receive excess organic matter leading to an enhancement of benthic CO_2 fluxes from the oxidation of the
263   organic matter (Burford & Langton 2001), N_2O will be emitted from aquaculture systems primarily as a by-
264   product of the conversion of ammonia (contained in fish urea) to nitrate through nitrification and nitrate to N_2
265   gas through denitrification (Hu et al., 2012). While CH_4 production may occur if bottom muds are anoxic, some
266   of the CH_4 will be oxidized as it passes through the water column, which must be oxygenated for fish culturing
267   (Bose et al., 1991). However, there is considerable uncertainty regarding N_2O and CH_4 fluxes associated with
268   aquaculture and additional research is necessary. When stocking of the ponds is discontinued, the ponds are
269   abandoned. On abandonment, the area utilized for aquaculture is often left with saturated soils. In this guidance,
270   this Chapter covers CO_2 emissions and removals from all phases of aquaculture and N_2O emissions only during
271   the period when the ponds are being stocked.

272   *Seagrass Meadows.* Fish farming is a rapidly expanding industry in Asia (FAO 2007a). The fish are retained in
273   floating cages or pens made up of nets often fastened to bamboo sticks that are anchored in the sediment (Alongi
274   et al., 2009). Fish farming generates organic waste that impacts the immediate environment resulting in nutrient
275   enrichment of the water column and organic enrichment of sediments beneath the farm. Nutrient over-
276   enrichment of seagrass meadows has led to water and sediment quality deterioration, algal overgrowth, and loss
277   of seagrass (Apostolaki et al., 2010; Apostolaki et al., 2011). Increased organic matter accumulation increases
278   benthic metabolism leading to anoxic conditions and high sediment sulfide concentrations have been associated
279   with seagrass die-off events (Holmer & Heilskov 2000; Borum et al., 2005). Gas bubbles have been observed in
280   the sediments underlying fish pens and the sulphate concentration were depleted in the surface layers, thus it is
281   thus likely that methane production occurs in these settings but no measurements have been made to date
282   (Holmer et al., 2002).

283   **Salt production**

284   *Mangrove Forests and Tidal Marshes.* The Ramsar convention recognizes salt exploitation sites or solar salterns
285   as a type of wetland. These are sites where salt is produced by evaporating seawater. The area covered can be

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286 extensive and sites are found along tropical and subtropical coasts worldwide (Oren 2009). Many solar salterns
287 have long histories, on the order of centuries (Thiery and Puente 2002). More recently, salt production has been
288 shown to displace mangroves on the coast of Java (Sukardjo 1993). Some production sites, as in San Francisco
289 Bay and on the Camargue, have been abandoned and restoration activities are underway. Establishment of the
290 production system is similar to the construction phase of aquaculture and can include clearing vegetation,
291 levelling, diking and constructing channels to develop a multi-pond production system (Oren 2002). Scientific
292 evidence is not adequately developed to provide default emission factors for effects on CO_2 emissions while the
293 salt production ponds are in use. The CO_2 emissions and removals of salt production are similar as those of
294 aquaculture during construction and abandonment and so similar guidance in given in both instances.

295 **Extraction (dredging; port, harbour and marina construction; filling)**

296 *Mangrove Forests and Tidal Marshes.* Dredging excavates soil often leading to loss of coastal wetlands. In
297 mangrove forests and tidal marshes this most often occurs by direct physical removal of biomass and soil. The
298 CO_2 emissions and removals associated with this extraction are the same as those of aquaculture during
299 construction and so the same guidance in given in both instances. The area that has had the soil removed is
300 sometimes subsequently filled with other soil, whether extracted within or outside the coastal ecosystem. Filling
301 of coastal wetlands is also considered a significant management activity affecting CO_2 emissions; if filling
302 occurs, it is preceded by extraction. Similarly as for extraction, CO_2 emissions and removals must be reported.
303 Once the extraction is complete, the area that has had the soil removed may become covered with water and CO_2
304 emissions are assumed to be negligible.

305 *Seagrass Meadows.* Extraction effects on seagrass meadows can take two forms: 1) direct via on-site physical
306 removal of soil and biomass (Zainal et al. 1993. Ertlinmeyer et al 2012) or 2) indirect via sediment resuspension
307 that causes high turbidity and reduces water quality impacting biomass stocks through inhibition of
308 photosynthesis (Erftemeijer and Lewis, 2006) leading to major die back (Cyrus et al. 2008) and/or seagrass loss
309 (Cabaço et al. 2008). The direct effects of extractionon seagrass meadows are when soil is removed todeepen and
310 maintain navigation channels and harbour entrances or for extraction of fill materials from seagrass meadows
311 (Larkum and West 1990; Da Silva et al. 2004). These activities have been reported to represent the greatest
312 environmental threats to seagrass meadows, particularly in the Gulf region where more than 40% of the coastline
313 has now been modified and developed (Sheppard and Price, 1991).The indirect effects of extraction can result
314 from any significant dredging activity (i.e. beach renourishment, channel dredging or widening, changes in land
315 catchments, etc) that occurs landward of seagrass meadows. The CO_2 emissions and removals associated with
316 extraction (direct physical removal of biomass and soil) are similar to those of aquaculture during construction
317 and so similar guidance is given).

318 **Harvesting of aquatic resources**

319 *Mangrove Forests.* Throughout the tropics, mangrove wood is harvested for fuel, charcoal, and construction
320 (Ellison and Farnsworth 1996, Walters et al. 2008). Harvesting can range from extensive forest clearing, to more
321 moderate, selective harvesting of individual trees to minimally invasive incidental bark removal. In wetlands
322 dominated by woody vegetation change in biomass C stocks should be considered during both selective
323 harvesting and forest clearance. CO_2 emissions from soils due to forest clearing should also be considered in C
324 stock estimations (Alongi et al. 1998). To date, there have been no studies that suggest a change in N_2O
325 emissions with harvests. Plant-mediated transport of methane has been documented (Kreuzwieser et al. 2003;
326 Cheng et al. 2007), but few data are currently available.

327 *Tidal Marshes.* Harvesting of marsh vegetation is assumed to have negligible impacts on biomass and soil C
328 stocks. However, in cases where extensive harvesting of vegetation or grazing is known to occur, it is good
329 practice to document and report the CO_2 emissions and removals associated with this activity.

330 *Seagrass Meadows.* Physical disturbance is an issue with harvesting marine resources such as bivalves and other
331 shellfish. On-ground shellfish culture and harvest methods can result in trampling and disturbance from boat
332 wakes and propeller scars in shallow waters (Dumbauld et al. 2009). Intertidal seagrass beds can be particularly
333 impacted by bait collection, through digging and trenching as well as pumping of sediment for prawns (Pillay et
334 al. 2010) and associated trampling. Thus, harvesting of aquatic resources can have impacts on CO_2 emissions
335 and removals primarily through changes in biomass C stocks where seagrass meadows have been lost.

336 **Nutrient enrichment**

337 Human activities can provide excess organic matter, nitrogen and phosphorus to coastal waters through
338 agriculture runoff, discharge of sewage and industry effluent (Seitzinger and Harrison 2008). Nutrient

339   enrichment stimulates algal production, adding to organic matter loads in coastal waters. Nitrate, ammonium and
340   dissolved organic N are the major forms of N input (Dai et al. 2008, Seitzinger and Harrison 2008).
341   Decomposition of organic matter and nutrients supplied through anthropogenic sources can result in enhanced
342   emissions of greenhouse gases.

343   *Mangrove Forests and Tidal Marshes.* In mangrove forests and tidal marshes, the effects nutrient availability on
344   plant community structure and aboveground and belowground biomass is not well understood. Numerous
345   fertilization experiments indicate that aboveground production in saline wetlands is limited by availability of N,
346   while tidal freshwater marshes may be limited by availability of P (Megonigal and Neubauer 2009). Fertilization
347   with N in tidal salt marshes has resulted in an increase in plant height, photosynthetic rates, and aboveground
348   biomass production (e.g. Valiela and Teal 1974; Leendertse et al., 1997; Pennings et al., 2002). However,
349   belowground production decreases with increased nutrient supply (Valiela et al., 1976; Darby and Turner 2008;
350   Deegan et al., 2012). Since belowground production is the major source of carbon sequestered in marsh and
351   mangrove soils, fertilization may result in no, or perhaps decreased, rates of carbon sequestration (Deegan et al.
352   2012). However, scientific evidence is not adequately developed to provide default emission factors for nutrient
353   enrichment effects on CO_2 emissions and removals associated with biomass or soils in mangrove forests and
354   tidal marshes. For instance, most mangrove research has focused on short-term increases in foliage nutrient
355   content (e.g., Simpson et al., 2013) than on actual measurement of increases in biomass over time and the rate of
356   increase in biomass increases initially with rate of nutrient supply (Alongi 2011). Thus, for the management
357   activity nutrient enrichment, this chapter covers only CH_4 emissions due to effluent from aquaculture and
358   urbanisation of the coastal zone and agricultural run-off and N_2O due to effluent from aquaculture. For non-CO_2
359   gases associated with other types of nutrient enrichment, covers N_2O emissions from agricultural run-off
360   (through N leaching from application of N to terrestrial soils) are covered in Chapter 11, Volume 4 of the *2006*
361   *IPCC Guidelines.* In this Supplement, N_2O and CH_4 emissions from waste water (including sewage) are covered
362   in Chapter 6 on semi-natural treatment wetlands.

363   *Seagrass Meadows.* Decline of seagrass populations associated with anthropogenic nutrient loading including
364   effluent from aquaculture (Yang and Yang, 2009) has been observed in many estuarine embayments (Waycott et
365   al. 2009). Increased availability of nutrients may lead to blooms of macroalgae, phytoplankton, and epiphytes, all
366   of which shade seagrass, reducing the light available for photosynthesis that can lead to seagrass loss (Waycott et
367   al. 2009). Because the effects due to agricultural run-off and effluent discharge from aquaculture result in a
368   decrease in both aboveground and belowground biomass stocks as well as increased CO_2 emissions from soils,
369   with sufficient scientific evidence of both, CO_2 emissions and removals due to nutrient enrichment are covered
370   in this Chapter.

371   **Hydrologic/Sediment diversion (soil elevation loss)**
372   *Mangrove Forests and Tidal Marshes.* The processes by which elevation in tidal wetlands is maintained against
373   sea level rise and in some cases, coastal subsidence, rely upon the supply of mineral soils (Kirwan et al., 2011)
374   derived from nearby rivers, cliffs, seabeds and oceanic import as well as growth of belowground biomass to
375   maintain elevations against sea level rise. Therefore management practices that alter soil supply or cause
376   subsidence will impact on coastal ecosystems. For example, many coastal wetlands are impacted by upstream
377   diversions of water, such as from the construction of dams that is accompanied by diversion of sediment
378   resulting in sediment starvation. Reduction of sediment delivery brought about by coastal structures can also
379   result in sediment starvation, erosion of coastal wetland soils and release of stored carbon. Oil and gas extraction
380   also affects coastal wetlands and results in soil subsidence and vegetation drowning in coastal areas (Craig et al.
381   1979; Dahl 2011). Thus hydrologic diversion from coastal areas with mangrove forests and tidal marshes,
382   resulting in reduced elevation relative to sea-level rise or subsidence, can cause significant impacts to above and
383   belowground C stocks if the soil becomes subtidal. As C in decayed vegetation is released to the water column
384   and to the atmosphere, these C stock changes should be reported.

385   **Drainage**
386   *Mangrove Forests and Tidal Marshes.* Coastal wetlands have been diked and drained to create agricultural land
387   (pasture and croplands) and settlement since before the 11th century (Gedan et al., 2009). The practice continues
388   today on many coastlines. On some diked coasts, groundwater of reclaimed former wetlands is pumped out to
389   maintain the water table at an optimum level below a dry soil surface while on other coasts drainage is achieved
390   through a system of ditches and tidal gates. Drainage causes a reduction in the degree of soil saturation and
391   ordinarily increases rates of organic matter decomposition, resulting in loss of soil carbon (Armentano and
392   Menges 1986). This response will vary regionally with climate (Pozo and Colino 1992) and locally with soil
393   salinity, soil texture, and the quantity of labile organic matter available in the drained soil (Heminga et al., 1998;
394   Setia et al., 2011). Drainage can also lead to CO_2 emissions due to oxidation of dissolved organic and particulate

395   organic carbon in the water carried by drainage channels (see Annex 4.2). Drainage could be accompanied by
396   land clearing, resulting in changes in biomass and soil carbon pools. If burning accompanies drainage, emissions
397   from changes in those C pools (e.g. DOM) should also be reported.

398   **Restoration and Creation.**
399   *Mangrove Forests and Tidal Marshes.* Rewetting as a component of restoration, results where hydrologic
400   modifications reverse drainage or remove impoundments or other obstructions to hydrologic flow (i.e. levee
401   breach). Rewetting of drained soils through reconnection of hydrology can reduce oxidation of soil C but may
402   lead to CH_4 emissions depending on salinity of reintroduced water (Harris et al 2010). The reestablishment of
403   vegetation can reinitiate soil carbon sequestration leading to wetland restoration. Improved estimates of soil
404   carbon accumulation rates in mangroves and tidal marshes (Chmura et al. 2003, Breithaup et al., 2012) have
405   recently been obtained making it possible to quantify C gains in restored systems. Also included in this activity
406   are created mangrove forests and tidal marshes that are typically established by removing the upper layer of
407   upland soil or dredge spoil and grading the site until the appropriate tidal elevation is reached. Hence, the initial
408   soils at created wetland sites are typically upland soils and/or dredge spoil. A peat layer can eventually develop
409   in the surface soils with soil properties equivalent to soil properties within the upper layer of natural wetlands
410   (Osland et al. 2012). Mangrove forests can also be created through high riverine sediment load, leading to rapid
411   sediment accumulation, so that previously sub-aqueous soils can be elevated above tidal influence. This naturally
412   created land can be naturally or purposefully vegetated. Time lags for equivalence of C pools between created
413   and natural mangrove sites also suggest a timescale of ~20 years for restoration of functionally equivalent soil C
414   accumulation rates (Craft et al. 2003, Osland et al . 2012).
415   *Seagrass Meadows.* Water quality improvements can reverse seagrass loss due to increased light penetration.
416   The re-establishment of seagrass vegetation can increase C gains, albeit slowly. For example, a 3-5 year time lag
417   between nutrient load reduction and initiation of seagrass recolonization has been observed (Vaudrey et al. 2010),
418   with a further 12-15 yr time lag before seagrass biomass attains a relatively stable distribution with potential for
419   soil carbon accumulation rates equivalent to natural settings (McGlathery et al., 2012). Restoration of sites
420   previously supporting seagrass meadows can be mediated by purposeful dispersal of seed or planting of seagrass
421   modules (Orth et al., 2012). These same techniques can also be used to create new seagrass meadows (Jones et
422   al., 2012)

423   **Other Activities.**
424   *Mangrove Forests, Tidal Marshes and Seagrass Meadows.* In order not to omit any potentially significant
425   management activity that may now or in the future constitute significant CO_2 emissions or removals or emissions
426   of non-CO_2 gases, a final subtype "other activities" is identified. For example, currently salt production is
427   currently not considered a management activity that significantly impacts seagrass meadows and thus no Tier 1
428   guidance is provided However, as economic or social conditions change, so might management practices. Thus,
429   the management activity termed, other activities, is provided to capture such potential changes in conditions.

430   # 4.1.2   Conversion from a land-use category that includes
431   # coastal wetlands

432   This section covers coastal wetland ecosystems that have been converted from the Wetlands land-use category to
433   other land-use categories (see Section 4.3 for further guidance). Drainage or extraction are activities that are
434   most likely to result in land-use category conversion from Wetlands to another IPCC land-use category, however,
435   this is largely a function of how the land is classified (see Box 4.1). Excavation of soil may also result in
436   conversion to Settlements. However, not all cases of land-use conversion result from drainage or extraction. For
437   example, in the case of forested coastal wetland ecosystems, a land-use conversion can occur simply based on
438   how the land is classified. For example, a mangrove forest that was cleared for timber harvest or otherwise
439   deforested could undergo a change in land-use category if the mangrove forest had been classified as Forest land,
440   but would not undergo a change in land-use category if the mangrove forest had been classified as Wetlands.
441   Although the scale and resulting management activity may result in a land-use category change, the
442   methodology to estimate CO_2 emissions is the same as given in section 4.1.1. There are cases in which a change
443   in land-use category involves implementation of new methodologies and emission factors. For example, if a
444   coastal wetland is drained to the extent that it is dry all year round, it does not meet the definition of wetlands as
445   presented in this Chapter. Thus, a new land-use category would necessarily be applied. In the case that the
446   coastal wetland has organic soils and is permanently drained wetland, refer to Chapter 2 of this Supplement (see

447   Box 4.1 for further examples). If conversion results in a land-use category with mineral soils, refer to the
448   respective Chapter in the *2006 IPCC Guidelines*.

449   # 4.1.3   Conversion to a land-use category that includes
450   # coastal wetlands

451   This section considers rewetting and restoration or creation of coastal wetlands that occurs where hydrology,
452   water quality or soils have been altered for establishment and survival of functioning vegetation (see Section 4.4
453   for further guidance). This includes restoration of coastal wetlands, where vegetation that was present prior to
454   the current land use has been re-established, or creation, where actions have been taken to develop coastal
455   wetlands in areas where they cannot be confirmed to have occurred previously.

456

457   # 4.2   LAND REMAINING IN A LAND-USE
458   # CATEGORY

459   This section details methodology necessary to estimate impacts of various human activities on greenhouse gas
460   emissions from Land remaining in a land-use category. Sub-sections detail the methods for estimates as a result
461   of change in biomass (subsection 4.2.1), DOM (subsection 4.2.2), soil (subsection 4.2.3), and for non-CO_2 gases
462   (sub-section 4.2.4). Methods for biomass, DOM and non-CO_2 gases in large part reference the methodological
463   guidance of the *2006 IPCC Guidelines* which should be read before and referred to in conjunction with, this
464   guidance.

465   Guidance is provided here on estimating greenhouse gas emissions from management activities that do not result
466   in a land-use conversion. These activities either take place without any changes of the water table over all land
467   area (e.g. nutrient enrichment, harvesting of aquatic resources) or over part of the land area (e.g. salt production,
468   extraction) within the managed coastal wetland. If these management activities can result in a change from the
469   coastal wetland land-use category to another IPCC land-use category, then they will be considered in section 4.3.

470   The general approach that is applied combines the change in CO_2 emissions and removals for each activity
471   summed for each pool with non-CO_2 gases treated separately. The following equation (Equation 4.1) is used for
472   each of the carbon pools:

EQUATION 4.1

ANNUAL CHANGE IN CARBON POOLS IN LAND REMAINING IN A LAND USE CATEGORY

$$\sum \Delta C_{pool(1...i)} =$$
$$\Delta C_{AQ} + \Delta C_{SP} + \Delta C_{EXT} + \Delta C_{HARV} + \Delta C_{NUTR} + \Delta C_{DIV} + \Delta C_{DR} + \Delta C_{RES} + \Delta C_{CRE}$$

---

477   where:

478        $\sum \Delta C_{pool(1...i)}$ = the sum of carbon stock changes for each pool with activities summed within each pool
479   from 1 to i activities.

480   ΔC_{AQ} = Change in carbon stocks associated with aquaculture activity

481   ΔC_{SP} = Change in carbon stocks associated with salt production activity

482   ΔC_{EXT} = Change in carbon stocks associated with extraction activity

483   ΔC_{HARV} = Change in carbon stocks associated with harvesting activity

484   ΔC_{NUTR} = Change in carbon stocks associated with nutrient enrichment activity

485   ΔC_{DIV} = Change in carbon stocks associated with hydrologic/sediment diversion activity

486   ΔC_{DR} = Change in carbon stocks associated with drainage activity

487   ΔC_{RES} = Change in carbon stocks associated with restoration activity

488   ΔC_{CRE} = Change in carbon stocks associated with creation activity

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489 4.2.1 Biomass

490 This section addresses estimation of changes in aboveground and belowground biomass carbon pools associated
491 with management activities in coastal wetlands in all categories i.e. land remaining in a land-use category,
492 conversion from a land-use category that includes coastal wetlands and conversion to a land-use category that
493 includes coastal wetlands. It builds on the *2006 IPCC Guidelines* and the *Good Practice Guidance for Land Use,*
494 *Land-Use Change and Forestry (GPG-LULUCF)*. For coastal wetlands with mangroves forest changes in
495 biomass carbon stocks follow equations provided in Chapters 2 and 4, Volume 4, of the *2006 IPCC Guidelines.*
496 For managed coastal wetlands with tidal marshes and seagrass meadows, changes in biomass carbon stocks
497 follow largely follow equations in the Chapters 2 and 6, Volume 4, of the *2006 IPCC Guidelines*. However,
498 there are some deviations from these general methods as applied to the Land Remaining in a land-use category
499 guidance as presented in Volume 4 of the *2006 IPCC Guidelines*. Thus, Table 4.2 should be used to identify the
500 appropriate Tier 1 approaches and equations that should be applied when following this guidance. The main Tier
501 1 approaches and equations for each activity are presented in Table 4.2 below.

502

TABLE 4.2 MANAGEMENT ACTIVITIES, TIER 1 EQUATIONS OR DEFAULT EF FOR BIOMASS POOL CHANGES		
Activity	**Ecosystem**	**Tier 1 Equation[1] and Default EF**
Aquaculture (ΔC_{B-AQ}), Salt Production (ΔC_{B-SP}), Extraction (ΔC_{B-EXT})	Mangrove forest	**AQ, SP, EXT-D**[2]: at start of activity, apply Eq. 2.9 or 2.10 and Eq. 2.11 & 2.14; $\Delta C_G = 0$ and $\Delta C_L = L_{disturbance}$; Tabel 4.3 – 4.6 **AQ, SP**: for use phase, $\Delta C_G = \Delta C_L$; Table 4.3-4.6 **AQ, SP**: for abandonment phase, apply Eq. 2.9 or 2.10 and Eq. 2.11 - 2.14; Table 4.3-4.7
	Tidal marsh	**AQ, SP, EXT-D**[2]: at start of activity, apply Eq. 2.8a where $Ct_2=0$ and $Ct_1=$initial C stock[3]; Table 4.8 **AQ, SP**: for abandonment phase, apply Eq. 2.8a; Table 4.8 **AQ**: for use phase, $\Delta C_G = \Delta C_L$; Table 4.8
	Seagrass meadow	**AQ, EXT-D and EXT-I**[4]: at start of activity, apply Eq. 2.8a where $Ct_2=0$ and $Ct_1=$initial C stock[3]; Table 4.9-4.11
Harvesting of Aquatic Resources (ΔC_{B-HARV}), Hydrologic/Sediment Diversion (ΔC_{B-DIV})	Mangrove	Apply Eq. 2.9 or 2.10 and Eq. 2.11 - 2.14[5]; Table 4.3-4.6
	Tidal Marsh	Apply Eq. 2.8a; Table 4.8
	Seagrass Meadow	NA
Nutrient Enrichment (ΔC_{B-NUTR})	Mangrove	NA
	Tidal Marsh	
	Seagrass Meadow	**EXT-I**[4]: at start of activity, apply Eq. 2.8a where $Ct_2=0$ and $Ct_1=$initial C stock[3]; Table 4.9-4.11
Drainage (ΔC_{B-DR}), Restoration (ΔC_{B-RES}) & Creation (ΔC_{B-CRE}), Other Activities ($\Delta C_{B-OTHER}$)	Mangrove	**DR, RES, CR, OTHER**: apply Eq. 2.9 or 2.10 and Eq. 2.11 - 2.14; Table 4.3 – 4.7
	Tidal Marsh	**DR, RES, CR, OTHER**: apply Eq. 2.8a; Table 4.8
	Seagrass Meadow	**DR**: NA, **RES, CR, OTHER**: apply Eq. 2.8a; Table 4.9-4.11
Note -- [1]Equations in the section can be found in the 2006 IPCC Guidelines; [2] EXT-D = where biomassare is physically removed; [3]$Ct_1=$initial C stock can be found in Table 4.9-4.11; [4]EXT-I = biomass C stock change resulting from sediment deposition effects; [5]reporting $L_{disturbance}$ as loss due to harvest; NA = not applicable		

503

504 4.2.1.1 CHOICE OF METHOD

505 Removal or loss of biomass resulting from management activities that occur during aquaculture, salt production,
506 and extraction for mangrove forests, tidal marshes and seagrass meadows are estimated at Tier 1 level with the

507 key assumption that carbon in biomass lost in the year of the start of the activity is oxidised to CO_2 (Table 4.2).
508 For mangrove forests, this is estimated with the *Gain-Loss* method as $\Delta C_L = L_{disturbance}$. For tidal marshes and
509 seagrass meadows, this is estimated with the *Stock-Difference* method with the biomass C stock at $t_2 = 0$. For
510 harvesting of aquatic resources and hydrologic/sediment diversion, guidance follows equations provided in
511 Chapter 2 as noted in Table 4.2. For nutrient enrichment, change in biomass C stocks are only estimated for
512 seagrass meadows as EXT-I (indirect effect of extraction activity; see Section 4.1.1) and follows the *Stock-*
513 *Difference* approach with the biomass C stock at $t_2 = 0$ (lost in the year that the activity starts). For drainage,
514 restoration/creation and other activities, methodology follows guidance in *2006 IPCC Guidelines* as described in
515 Table 4.2 with the exception of drainage for seagrass meadows, an activity for which there is no evidence of its
516 occurrence.

517 **TIER 1**

518 **Mangrove, Tidal Marsh and Seagrass Meadow**

519 The method for estimating changes in mangrove biomass for Tier 1 follows Eq. 2.9 and Eq. 2.11-2.14 and for
520 tidal marsh and seagrass biomass Eq. 2.8a is applied (see Volume 4 of the *2006 IPCC Guidelines* for details).
521 Default values presented in Tables 4.3-4.11 are used in these equations, depending on whether the ecosystem is
522 mangrove forest, tidal marsh, or seagrass meadow and their climate domain. For mangroves, Tables 4.3-4.7
523 contain default factors for average aboveground biomass, the ratio of belowground to aboveground biomass, and
524 dry weight:carbon conversion factors, differentiated by humid and dry tropical regions and the subtropics. To
525 estimate losses due to wood-removals and fuelwood, wood density (Table 4.7) and BEF values should be applied
526 (Chapter 3 in 2003 *GPG-LULUCF*). For tidal marshes, Table 4.8 contains default factors for average
527 aboveground and belowground biomass by climate and salinity. For seagrass meadows, methodology also
528 generally follows the *Stock-Difference* approach with data provided for aboveground biomass, the ratio of
529 belowground to aboveground biomass and C conversion factors (Tables 4.9-4.11). It should be noted that the
530 loss of biomass C stock from seagrass meadows due to nutrient enrichment and indirect effects of extraction
531 results in loss of water clarity and light available (as described in Section 4.1.1) and should be reported.

532 **TIER 2**

533 Tier 2 methods are used where countries have country-specific emission factors, and substantial national data or
534 data that can be gathered based at reasonable cost. Country-defined methodology (e.g., high priority is empirical
535 measurement of above-ground biomass which for mangroves involves use of allometric equations) may be based
536 on detailed inventories of permanent sample plots for coastal wetlands. Tier 2 can include such other
537 improvements as, in the case of mangroves, use of allometric relationships to accurately measure aboveground
538 biomass; a priority in this case would be to measure diameter-at-breast height of trees in the permanent plots (see
539 Annex 4.3). To estimate carbon gain using country-specific annual increment, wood density (Table 4.7) and BEF
540 values should be applied (Chapter 3 in 2003 *GPG-LULUCF*). In the case of seagrasses, where extraction,
541 nutrient enrichment, or aquaculture resulting in either reduced water quality or redeposition of sediments is
542 significant leading to a land category or pool that is key, Tier 2 methods can involve data collected from
543 permanent sample plots or other means of acquiring country-specific data as covered in standard texts. For
544 seagrass meadows, the lag time between water clarity impacts and biomass C stock change could be employed
545 where t_2 was estimated as a fraction of initial stock.

546 **TIER 3**

547 Tier 3 approach for biomass carbon stock change estimation allows for a variety of methods, including process
548 based models. Implementation may differ from one country to another, due to differences in inventory methods,
549 coastal wetland conditions and activity data. Tier 3 requires use of detailed national coastal wetland inventories.
550 They may be supplemented by allometric equations and models calibrated to national circumstances that allow
551 for direct estimation of biomass growth. Tier 3 could also involve inventory systems using statistically-based
552 sampling of biomass over time and/or process models, to further stratify ecosystem type into subtype, ecological
553 zone and salinity.

554 ## 4.2.1.2   CHOICE OF EMISSION/REMOVAL FACTORS

555 **TIER 1**

556 **Mangrove, Tidal Marsh and Seagrass Meadow**

557 Countries using a Tier 1 method should utilize default data for mangrove forests, tidal marshes or seagrass
558 meadows provided in this guidance. For mangrove forests, prior to when or where aquaculture, salt production,
559 extraction or harvesting, or hydrologic/sediment diversion occurred, Tier 1 emission factors for biomass stocks
560 can be calculated using a *Stock-Difference* approach or a *Gain-Loss* approach using biomass growth, primarily
561 differentiated at the level of climate domain (and in the case of tidal marshes, also by salinity for the temperate
562 climate domain). For mangrove forests, the use of Tables 4.3 – 4.7 including guidance on estimating BCEF
563 based on woody density for losses of fuelwood and wood-removals found in the *2006 IPCC Guidelines* are
564 needed. For tidal marshes, the default emissions factors to be used are in Tables 4.8. For seagrass, emission
565 factors found in Tables 4.9-4.11.

566 **TIER 2**

567 The higher Tier methods described in Chapter 2 of the *2006 IPCC Guidelines* (Eq. 2.18-2.23) will permit better
568 estimates when national data are applied. Estimate of loss of below-ground root biomass should also be
569 empirically measured rather than using the ratio of aboveground to belowground biomass.

570 **TIER 3**

571 Tier 3 modelling would include country-specific emission factors derived or modelled from measurement data.
572 The models should capture variation in emission rates driven by extent and depth of biomass extraction and in
573 the case of water/sediment diversion, the rate of biomass decline. The incremental growth rates of the dominant
574 species can be multiplied by the current biomass estimate to derive a figure of projected change over time, if
575 required. For seagrass meadows, aerial photographs may be used in regions of high water clarity, good contrast
576 between seagrass meadows and soil and low cover of other macrophytes. Field validations can be implemented
577 to verify model output using field measurements by diving or underwater camera. Other examples of data
578 improvements for aquaculture, salt production and extraction, for example, include ground-truth estimates of
579 total area impacted, the depth at which removal of biomass has occurred or the completeness of biomass removal
580 could also be verified. Furthermore, with indirect effects of extraction on seagrass meadows, because the time
581 periods for biomass loss will vary based on national circumstances, some seagrass meadows will show more
582 rapid decline than seagrass meadows in other areas. Total areas can be estimated with greatest certainty coupling
583 aerial or remote sensing with field measurements.

584 ## 4.2.1.3 CHOICE OF ACTIVITY DATA

585 All tiers require information on areas of managed coastal wetlands for ecosystem types, climate, and
586 management activities which vary depending on national circumstances. The default methodology for all Tier 1
587 estimates requires data on the area of managed wetland, the type and dominant species present in the wetland,
588 and soil type. The type of wetland present as well as soil type can be obtained from national wetland and soil
589 type maps (if available or the International Soil Reference and Information Centre; www.isrig.org); wetland
590 distributions for most countries can be obtained from the RAMSAR web site (www.ramsar.org). When
591 information is gathered from multiple sources, cross-checks should be made to ensure complete and consistent
592 representation and avoid omissions and double-counting. Please refer to the extended list of activity data sources
593 in Annex 4.2 in this Chapter.

594 **Aquaculture, Salt production**
595 The ponds or structures used to create conditions conducive to aquaculture and salt production can be identified
596 from aerial photographs or by inspection and measurement of the total area where biomass has been removed.
597 Information on regional aquaculture projects worldwide can be obtained from the GISFish database of the FAO
598 (www.fao.org) and similar project information for salt production projects can be obtained from the Salt Institute
599 at www.saltinstitute.org.

600 **Extraction or Harvesting**
601 Information of current extraction/harvesting projects may be obtained from local, state or regional government
602 department websites as many countries and regional government authorities require documentation of
603 environmental impact assessments. For seagrass meadows, aerial photographs may be used in regions of high
604 water clarity, good contrast between seagrass and soil and low cover of other macrophytes. If these conditions
605 are not present, remote sensing imagery providing data on water clarity using intensity of chlorophyll or
606 concentration of suspended particles other photoimagery can be used and readily available.

607 **Nutrient enrichment**

608 We can expect to find nutrient-affected systems downstream of major urban centers, municipal sewage treatment
609 facilities, and watersheds where a large portion of the land is under intensive agricultural use. For seagrass
610 meadows the N load per estuary that relates to complete loss of seagrass has been predicted to be at loading
611 values between 100 and 175 kg N ha^{-1} yr^{-1} (Steward and Green 2007; Latimer and Rego 2010). Information
612 about changes in seagrass biomass as a result of nutrient enrichment may be obtained from national government
613 departments, marine conservation trusts and societies and global seagrass networks (http://seagrasswatch.org).
614 Review papers in the scientific literature (e.g. Waycott et al., 2009) have collated information on localised
615 seagrass loss. Historical records of seagrass cover including aerial photographs may be used in regions of high
616 water clarity, good contrast between seagrass and soil and low cover of other macrophytes.

617 **Hydrologic/Sediment Diversion, Drainage**
618 Total areas impacted by upstream diversions of water and sediment result in soil elevation loss and coastal
619 subsidence can be assessed using aerial or remotely sensed data as well as reports from Environmental ministries
620 or other agencies reporting rates of coastal subsidence and at higher Tiers validated with field measurements.
621 Drainage is recognized by presence of levees and rectilinear channel networks that stand out in comparison to
622 the normally flat surface with curving, bifurcating channels. Restoration would be recognized by the removal of
623 levees, tidal gates, enlargement of culverts, and possibly development of new hybrid channel networks that
624 incorporate both constructed and natural channels (MacDonald et al., 2010). Channels may visibly widen.
625 Immediately after rewetting, dead vegetation may be visible in tidal marshes, in both mangroves and tidal
626 marshes fresh mud will be deposited over previous soil surface. These information can be easily detected on
627 aerial images that are freely available. If following Approach 1 for land classification, information of drainage
628 and diversion projects may be obtained from local, state or regional government department websites as many
629 countries and regional government authorities require documentation of environmental impact assessments for
630 these activities.

631 **Restoration/Creation**
632 Estimates of biomass change as a result of wetland restoration or creation requires knowledge of previous
633 wetland coverage (in the case of restoration) and of biomass growth rates (in the case of restoration or creation).
634 Historical photos may be used to most readily estimate the pre-restored wetland area. Information on regional
635 wetland restoration and creation projects worldwide can be obtained from the Global Gateway to Geographic
636 Information Systems of the FAO (www.fao.org) as well as from the websites, www.wetlands.org and
637 www.globalrestorationnetwork.org.

Table 4.3 Carbon content of aboveground mangrove forest biomass ((gC/100gDW) or % DW)				
Component	**%C**	**95% CI**	**Range**	**References**
Leaves	45.0 (n = 35)	42.8, 47.3	42.3-50.9	Spain and Holt, 1980; Saenger, 2002; Alongi et al., 2003; 2004; Kristensen et al., 2008
Wood (stems + branches)	45.4 (n = 12)	43.1, 47.7	41.6-47.2	Spain and Holt, 1980; Gong and Ong, 1990; Twilley et al., 1992; Bouillon et al., 2007; Alongi et al., 2003, 2004

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Table 4.4 Aboveground Biomass in Mangrove forests (tonnes DW. ha^{-1})				
Domain	**Region**	**Aboveground biomass**	**95%CI**	**Range**
Tropical	Tropical Wet	196 (n=53)[1]	186, 205	3.7-557
	Tropical Dry	92 (n = 13)[2]	88, 97	3.2-201
Subtropical		75 (n= 10)[3]	76, 84	3.9-129

[1]References: Golley et al., 1975; Christensen, 1978; Ong et al., 1982; Putz and Chan, 1986; Tamai et al., 1986; Komiyama et al., 1987, 1988, 2000, 2008; Lin et al., 1990; Mall et al., 1991; Amarasinghe and Balasubramaniam, 1992; Kusmana et al., 1992; Slim et al., 1996; Fromard et al., 1998; Norhayati and Latiff, 2001; Poungparn, 2003; Sherman et al., 2003; Juliana and Nizam, 2004; Kirui et al., 2006; Kairo et al., 2008; Fatoyinbo et al. 2008; Camacho et al., 2011; Kauffman et al., 2011;Thant and Kanzaki, 2011.

[2]References: Golley et al, 1962; Briggs, 1977; Suzuki and Tagawa, 1983; Steinke et al., 1995; Alongi et al., 2003; Medeiros and Sampoia, 2008; Khan et al., 2009.

[3]References: Lugo and Snedaker, 1974; Woofroffe, 1985; Lee, 1990; Mackey, 1993; Tam et al., 1995; Saintilan, 1997; Ross et al., 2001; Coronado-Molina et al., 2004; Simard et al., 2006; Fatoyinbo et al., 2008; Komiyama et al., 2008; Abohassan et al., 2012.

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Table 4.5 Aboveground biomass growth in mangrove forests (tonnes DW ha^{-1} yr^{-1})				
Domain	Region	Aboveground biomass growth	95%CI	Range
Tropical	Tropical Wet	9.9 (n=23)[1]	9.4, 10.4	0.1-27.4
	Tropical Dry	3.3 (n = 6)[1]	3.1, 3.5	0.1-7.5
Subtropical		18.1 (n= 4)[1]	17.1, 19.1	5.3-29.1
[1]References: Ajonina 2008; Kairo et al., 2008; Alongi 2010				

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Table 4.6 Ratio of belowground biomass to aboveground biomass (R) in mangroves forests				
Domain	Region	R	95%CI	Range
Tropical	Tropical Humid	0.49 (n=18)[1]	0.47, 0.51	0.04-1.1
	Tropical Dry	0.29 (n = 9)[2]	0.28, 0.30	0.09-0.79
Subtropical		0.96 (n= 18)[3]	0.91, 1.0	0.22-267
[1]References: Golley et al., 1975; Tamai et al., 1986; Komiyama et al., 1987, 1988; Gong and Ong, 1990; Lin and Lu 1990; Tam et al., 1995; Poungparn, 2003 [2]References: Golley et al, 1962; Alongi et al., 2003; Hoque et al., 2010. [3]References: Briggs, 1977; Lin, 1989; Saintilan, 1997.				

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TABLE 4.7. WOOD DENSITY (D) OF COMMON MANGROVE TREE SPECIES			
Bruguiera gymnorrhiza	0.74	Heritiera littoralis	0.8
Xylocarpus mekongensis	0.72	Heritiera fomes	1.1
Xylocarpus granatum	0.7	Excoecaria agallocha	0.45
Sonneratia apetala	0.56	Ceriops tagal	1.1
Sonneratia alba	0.08	Ceriops decandra	0.96
Rhizophora mucronata	1.1	Bruguiera gymnorrhiza	0.86
Rhizophora mangle	0.83	Avicennia officinalis	0.67
Rhizophora apiculata	1.1	Avicennia marina	0.9
Laguncularia racemosa	0.6	Avicennia germinans	0.66
Site average of above values		0.77	
Data sources: Kauffman and Donato, 2012; Bosire et al., 2012.			

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TABLE 4.8 ABOVEGROUND AND BELOWGROUND BIOMASS FOR TIDAL MARSHES (TONNES C HA^{-1})								
Salinity	Domain	Region	Above-ground biomass	95% CI	n	Below-ground biomass	95% CI	n
Oligohaline to polyhaline	Subtropical	Warm temperate moist[1]	1.40	1.35, 1.44	3	9.2	8.58, 9.80	2
		Warm temperate dry[2]	5.64	5.57, 5.71	11	11.02	10.89, 11.15	4
	Temperate[3]		3.32	3.30, 3.34	91	23.9	23.37, 24.32	34
	Polar[4]		0.64	0.62, 0.66	3	ND[6]		
Tidal freshwater	Temperate[5]		4.03	4.00, 4.07	20	7.11	6.94, 7.18	8

Sources:

[1]AG: da Cunha Lana et al. 1991; Kirby and Gosselink 1976; Darby and Turner 2008; BG: da Cunha Lana et al. 1991; Darby and Turner 2008

[2]AG: Curco et al. 2002; Neves et al. 2007; Scarton et al . 2002; Linthust and Reimold 1978; Cartaxana and Catarina 1997; BG: Neves et al. 2007; Scarton et al. 2002; also referred to as Mediterranean

[3]AG: Benito and Onaindia 1991; Bouchard and Lefeuvre 2000; Boyer et al. 2000; Connor and Chmura 2000; Figueroa et al. 1988; Gallagher and Plumley 1979; Groenendijk 1984; Gross et al. 1986; Hopkinson et al. 1978; Hussey and Long 1982; Jeffrey and Hayes 2005; Jeffries et al. 1981; Jenssen 1980; Keefe and Boynton 1973; Ketner 1972; Kirby and Gosselink 1976; Kistritz et al 1983; Linthust and Reimold 1978; Mahall and Park 1976; Mendelsohn and Marcellus 1976; Morris and Haskin 1990; Pierce 1983; Schubauer and Hopkinson 1984; Smith et al. 1979; Squires and Good 1974; Whigham et al.1978; White et al. 1978; Williams and Murdoch 1972; BG: Boyer et al. 2000; Connor and Chmura 2000; Dame and Kenny 1986; Dunn 1981; Elsey-Quirk et al. 2011; Groenendijk and Vink-Lievaart 1987; Gross et al. 1991; Hussey and Long 1982; Kistritz et al. 1983; Livingstone and Patriquin 1981; Mahall and Park 1976; Roman and Daiber 1984; Smith et al. 1979; Whigham et al.1978

[4]AG: Curco et al. 2002; Neves et al. 2007; Scarton et al. 2002; Linthust and Reimold 1978; Cartaxana and Catarina 1997; BG: Neves et al. 2007; Scarton et al. 2002

[5]Birch and Cooley 1982; Doumlele 1981; Hopkinson et al. 1978; Whigham et al.1978

[6]No data available

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TABLE 4.9 ABOVEGROUND BIOMASS FOR SEAGRASS MEADOW				
Domain	**Aboveground biomass for seagrass meadow (tonnes DW ha^{-1})**	**95%CI**	**Range**	**n**
Tropical[1]	6.0	6.20, 7.89	0.1 – 75.4	137
Subtropical[2]	15.2	14.17, 16.26	1.2 - 810	260
Temperate[3]	19.9	18.16, 21.77	4.3 - 206	108

[1]Aioi & Pollard 1993, Brouns 1985, Brouns 1987b, Brouns & Heijs 1986, Daby 2003, de Iongh et al. 1995, Devereux et al. 2011, Fourqurean et al. 2012, Heijs 1984, Hertbert 1986, Holmer et al. 2001, Ismail 1993, Kaldy & Dunton 2000, Lee 1997, Lindeboom & Sandee 1989, Long et al. 1993, McDermid & Edward 1999, McKenzie 1994, Mellors et al. 2002, Moriarty et al. 1990, Nienhuis et al. 1989, Ogden & Ogden 1982, Paynter et al. 2001, Poovachiranon & Chansang 1994, Povidisa & Delefosse 2009, Rasheed 1999, Terrados et al. 1998, Uku & Bjork 2005, van Lent et al. 1991, van Tussenbroek 1998, Vermaat et al. 1993, Vermaat et al. 1995, Williams 1987.

[2]Aioi 1980, Aioi et al. 1981, Asmus et al. 2000, Bandeira 1997, Bandeira 2002, Boon 1986, Bulthuis & Woelkerling 1983, Burd & Dunton 2001, Cabaco et al 2012, Calleja et al. 2005, Cambridge & Hocking 1997, Carruthers 1994, Collier et al. 2009, de Boer 2000, Dillon 1971, Dixon & Leverone 1995, Dos Santos et al. 2012, Dunton 1990, Dunton 1994, Dunton 1996, Fourqurean et al. 2012, Goshima & Peterson 2012, Heck & Thoman 1984, Heijs 1984, Herbert & Fourqurean 2009, Herbert & Fourqurean 2008, Hillman et al. 1995, Holmer & Kendrick 2012, Holmer et al. 2004, Iverson & Bittaker 1986, James et al. 2009, Kaldy & Dunton 2000, Kenworthy & Thayer 1984, Kerr & Strother 1989, Kim et al. 2012, Kirkman & Cook 1987, Kirkman & Reid 1980, Kirkman & Reid 1979, Kirkman et al. 1982, Kowalski et al. 2009, Kraemer & Alberte 1993, Larkum et al. 1984, Lee & Dunton 1996, Lee et al. 2005, Lewis 1987, Longstaff et al 2000, Marba & Walker 1999, Masini et al. 2001, McGlathery et al. 2012, mcMahan 1968, McMahon & Lavery 2008, Meling-Lopez & Ibarra-Obando 1999, Moncreiff et al. 1992, Morgan & Kitting 1984, Mukai et al. 1979, Murray and Wetzel 1987, Nienhuis & Bree 1980, Odum 1963, Orth & Moore 1986, Paling & McComb 2000, Park et al. 2011, Perez-Llorens & Niell 1993, Perez-Ruzafa et al. 2012, Phillips et al. 1983, Powell 1989, Preen 1995, Reyes et al. 1995, Schwarz et al. 2006, Stevensen 1988, Terrados & Ros 1992, Thayer et al. 1977, Tomasko & Lapointe 1991, Townsend & Fonseca 1998, van Houte-Howes et al. 2004, van Lent et al. 1991, van Tussenbroek 1998, Walker 1985, Walker & McComb 1988, Walker et al. 1988, West & Larkum 1979, Yarbro & Carlson 2008, Zavodnik et al. 1998, Zieman et al. 1989.

[3]Auby & Labourg 1996, Bay 1984, Cebrian et al. 1997, Cebrián et al. 2000, Dennison & Alberte 1985, Duarte et al. 2002, Fourqurean et al. 2012, Guidetti et al. 2002, Gullstrom et al. 2012, Hebert et al. 2007, Jacobs 1979, Kaldy 2006, Kentula & McIntire 1986, Larned 2003, Laugier et al. 1999, Lillebo et al. 2006, Mann 1972, Marba & Duarte 2001, Martin et al. 2005, McRoy 1974, Nienhuis & Bree 1980, Nixon & Oviatt 1972, Olesen 1999, Olesen & Sand-Jensen 1993, Olesen & Sand-Jensen 1994, Ott 2008, Pedersen & Borum 1993, Perez & Romero 1994, Plus et al. 2003, Rismondo et al. 1997, Robertson & Mann 1984, Robertson & Mann 1974, Roman & Able 1988, Sand-Jensen & Borum 1983, Sfriso & Ghetti 1998, Terrados et al. 2006, Vermaat & Verhagen 1996, Vermaat et al. 1987, Zavodnik et al. 1998.

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TABLE 4.10 RATIO OF BELOWGROUND BIOMASS TO ABOVEGROUND BIOMASS (R) FOR SEAGRASS MEADOW				
Domain	**R**	**95%CI**	**Range**	**n**
Tropical[1]	1.7[1]	1.62, 1.78	0.05 – 25.62	396
Subtropical[2]	2.4[2]	2.33, 2.54	0.07 – 16.8	391
Temperate[3]	1.3[3]	1.18, 1.39	0.14 – 13.8	91

[1]Aioi & Pollard 1993, Brouns 1985, Brouns 1987, Coles et al. 1993, Daby 2003, Devereux et al. 2011, Fourqurean et al. 2012, Halun et al. 2002, Holmer et al. 2001, Ismail 1993, Lee 1997, Lindeboom & Sandee 1989, McKenzie 1994, Mellors et al. 2002, Moriarty et al. 1990, Nienhuis et al. 1989, Ogden & Ogden 1982, Paynter et al 2001, Poovachiranon & Chansang 1994, Povidisa et al. 2009, Rasheed 1999, Udy et al. 1999, van Lent et al. 1991, van Tussenbroek 1998, Vermaat et al. 1993, Vermaat et al. 1995, Williams 1987.

[2]Aioi 1980, Aioi et al. 1981, Asmus et al. 2000, Bandeira 2002, Boon 1986, Brun et al 2009, Collier et al. 2009, de Boer 2000, Devereux et al. 2011, Dixon & Leverone 1995, Dos Santos et al. 2012, Dunton 1996, Fourqurean et al. 2012, Hackney 2003, Herbert and Fourqurean 2009, Herbert & Fourqurean 2008, Holmer & Kendrick 2012, Jensen & Bell 2001, Kim et al. 2012, Kirkman & Reid 1979, Kowalski et al. 2009, Larkum et al. 1984, Lee et al. 2005, Lee et al. 2005b, Lipkin 1979, Longstaff et al. 1999, Masini et al. 2001, McGlathery et al. 2012, mcMahan 1968, Meling-Lopez & Ibarra-Obando 1999, Mukai et al. 1979, Paling & McComb 2000, Park et al. 2011, Powell 1989, Preen 1995, Schwarz et al. 2006, Stevensen 1988, Townsend & Fonseca 1998, Udy & Dennison 1997, van Houte-Howes et al. 2004, van Lent et al. 1991, van Tussenbroek 1998, Walker 1985, West & Larkum 1979, Yarbro & Carlson 2008.

[3]Agostini et al. 2003, Cebrian et al. 2000, Fourqurean et al. 2012, Hebert et al. 2007, Holmer & Kendrick 2012, Larned 2003, Lebreton et al. 2009, Lillebo et al. 2006, Marba & Duarte 2001, McRoy 1974, Olesen & Sand-Jensen 1994, Rismondo et al. 1997, Sand-Jensen & Borum 1983, Terrados et al. 2006

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Table 4.11 Carbon content of aboveground and belowground seagrass biomass ((gC/100gDW) or % DW)

Component	CF	95% CI	Range	References
Above ground biomass	33.4 (n = 72)	32.9, 33.9	23.6 – 43.8	Augier et al. 1982; Erftemeijer 1994; Fourqurean & Zieman 1992; Fourqurean et al. 1997; Fourqurean et al. 2007; Kenworthy & Thayer 1984; Longstaff & Dennison 1999; Mascaro et al. 2009; Mateo & Romero 1997; Nienhuis et al. 1989; Pergent et al. 1994; Plus et al. 2001; Rublee & Roman 1982; van Lent et al. 1991; Vinther & Holmer 2008; Wahbeh 1988.
Below ground biomass	32.3 (n = 50)	31.8, 32.9	24.7 – 42.1	Erftemeijer 1994; Kenworthy & Thayer 1984; Mascaro et al. 2009; Mateo & Romero 1997; Nienhuis et al. 1989; Plus et al. 2001; van Lent et al. 1991; Vinther & Holmer 2008; Wahbeh 1988.

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4.2.1.5 UNCERTAINTY ASSESSMENT

This section considers source-specific uncertainties relevant to inventory estimates. Estimating country-specific and/or disaggregated values requires more accurate information on uncertainties than given below. Chapter 3, Volume 1 of the *2006 IPCC Guidelines* provides information on uncertainties associated with sample-based studies. The literature available on uncertainty estimates on emission factors and activity data is limited. Seagrass aboveground biomass averages values from species that have very different leaf characteristics, resulting in a wide range of values. In the case of mangrove aboveground biomass, a comparatively large number of forest sites are extant, but the range of values is very large due to inherent differences in species composition, forest age, tidal height, and soil fertility. These uncertainties may be minimized as much as possible using Tier 2 or Tier 3 methods which can incorporate or classify forests by factors other than climate domain.

Variability in tidal marsh biomass will be due to differences in dominant species and competition between species, as well as salinity of flood waters, frequency of tidal flooding and climate. The high biomass in Mediterranean climates is due to the frequent dominance of perennial shrubs. For all vegetation there can be considerable yearly variability in production of biomass and seasonal variability in standing biomass. The empirical data available is biased by the prevalence of data from temperate regions and North America - the tidal fresh marsh data comes almost entirely from the Atlantic coast of the United States. Also lacking are data from boreal and subtropical marshes.

EMISSION AND REMOVAL FACTORS

The major sources of uncertainty for all wetland types are dominant species-specific differences in carbon content and differences as a function of ecosystem age, species composition, intertidal location, and community structure. As indicated in Tables 4.3 to 4.11, coefficients of variation range from about 24-200%. To reduce uncertainty, countries are encouraged to develop country- or region specific biomass expansion factors and BCEFs that fit their conditions. In case country- or regional-specific values are unavailable, the sources of default parameters should be checked and their correspondence with species present and specific conditions of a country should be examined.

The causes of variation of annual increment of mangrove growth include climate, site growth conditions, and soil fertility. Artificially regenerated and managed stands are less variable than natural forests. The major ways to improve accuracy of estimates of these wetlands are by application of country-specific or regional estimates of growth stratified by the dominant species present. If the default values of growth increments are used, the uncertainty of estimates should be clearly indicated and documented.

Tier 3 approaches can use growth curves stratified by species, ecological zones, site productivity and management intensity. For example, similar approaches are routinely used for mangroves in timber supply planning models and this information can be incorporated into carbon accounting models (e.g., Kurz et al., 2002).

For mangroves, data on commercial fellings are relatively accurate, although they may be incomplete or biased due to illegal fellings and underreporting due to tax regulations. Traditional wood that is gathered and used directly, without being sold, is not likely to be included in any statistics. Countries must carefully consider these

709 issues. The amount of wood removed from forests after storm breaks and pest outbreaks varies both in time and
710 volume. No default data can be provided on these types of losses. The uncertainties associated with these losses
711 can be estimated from the amount of damaged wood directly withdrawn from the forest or using data on
712 damaged wood subsequently used for commercial and other purposes. If fuelwood gathering is treated separately
713 from fellings, the relevant uncertainties might be high, due to high uncertainty associated with traditional
714 gathering.

715 4.2.2 Dead Organic Matter

716 The dead organic matter (DOM) pool in coastal wetlands includes coarse woody debris, fine litter, and dead
717 roots. Fine litter and dead wood are differentiated as fractions <10 cm and >10 cm diameter, respectively (Table
718 1.1, Chapter 1, Volume 4 of the *2006 IPCC Guidelines*). The dead roots less than 2 cm diameter are included in
719 the soil pool and not considered within the DOM pool. This fraction of dead roots turns over rapidly with the
720 assumption approximating steady state. DOM C stocks can vary depending on tidal inundation and frequency, as
721 well as soil oxidation and vegetation cover. Fine litter can be exported with tidal activity while a larger fraction
722 of senesced woody biomass is buried or decomposes *in-situ*. In wetlands, decomposition of DOM, especially
723 wood and coarse woody debris, is slow and accumulates as soil organic matter. In estimating inputs, outputs or
724 changes of DOM C stocks, careful consideration of pools should be made to avoid double-counting. Consistency
725 in how these fractions are determined and reported is good practice to avoid double-counting. DOM pools under
726 conditions of low soil oxidation-reduction potential that occur under saturated conditions can be large and when
727 exposed to oxidation constitute large CO_2 emissions. Thus, DOM C stock changes should be considered for the
728 activities as described above with changes in mangrove forest cover. This is a notable deviation from Tier 1
729 assumptions for Land Remaining in a Land-Use Category as laid out in the *2006 IPCC Guidelines* and is
730 necessary as certain types of management activities have large impacts on CO_2 emissions and removals without
731 resulting in a conversion to another IPCC land-use category.

732 General assumptions for estimating changes in the DOM pool can be differentiated between mangrove forest and
733 primarily non-woody coastal wetland types including tidal marsh and seagrass meadow. At Tier 1, tidal marsh
734 and seagrass meadow ecosystems are assumed to have relatively fast turnover of DOM and a steady-state
735 assumption applies. However, extensive management activities that result in vegetation or soil disturbance in
736 tidal marsh with perennial biomass could have large impacts on C emissions and removals. In Land remaining in
737 a land-use category, management activities where changes in the DOM pool are likely to be significant include
738 aquaculture, salt production, extraction, where the start of the activity results in loss of the DOM pool.
739 Methodologies for mangrove forests are supplied for Tier 1 estimation for management activities include
740 aquaculture, salt production, and extraction (Table 4.1). In these cases, DOM inputs may cease as extant
741 vegetation is cleared and DOM outputs are the extant stock of DOM. For drainage, DOM inputs may be
742 unchanged if there is no disturbance to the biomass pool and DOM outputs are equivalent to the stock of DOM
743 at the start of the activity where all C is assumed oxidized at Tier 1. For the harvesting activity and all other
744 activities that affect mangrove forests, generic equations provided in *2006 IPCC Guidelines* are directly
745 applicable. For all management activities that occur in tidal marsh and seagrass meadow, the change in C stocks
746 of DOM is assumed to be zero at Tier 1 (Table 4.12). If mangrove forest clearing is a significant activity, Tier 2
747 or 3 approaches should be used and the assumption of instantaneous oxidation of the DOM pool is not valid.
748 Both changes in dead wood and litter should be reported and summed to obtain changes in total dead organic
749 matter due to each activity as detailed in Table 4.12 below.

TABLE 4.12 MANAGEMENT ACTIVITIES, TIER 1 EQUATIONS AND DEFAULT EF FOR DEAD ORGANIC MATTER C POOL CHANGES		
Activity	Ecosystem	Tier 1 Equation[1] and Default EF

Aquaculture (ΔC_{DOM-AQ}), Salt Production (ΔC_{DOM-SP}), Extraction ($\Delta C_{DOM-EXT}$)	Mangrove forest	**AQ, SP, EXT-D**[2]: At start of activity, apply Eq. 2.18 or 2.19; $DOM_{in} = 0$ and $DOM_{out} = DOM$ oxidized upon disturbance; Table 4.13
		AQ, SP: for abandonment phase, apply Eq. 2.18 and 2.20 or 2.19; Table 4.13
		AQ: for use phase, $\Delta C = 0$
	Tidal marsh	$\Delta C = 0$
	Seagrass meadow	
Drainage (ΔC_{B-DR})	Mangrove forest	At start of activity, apply Eq. 2.18 and 2.20-2.22 or 2.19; $DOM_{out} = DOM$ oxidized upon disturbance ; Table 4.13
	Tidal marsh	$\Delta C = 0$
	Seagrass meadow	
Harvesting of Aquatic Resources ($\Delta C_{DOM-HARV}$), Nutrient Enrichment ($\Delta C_{DOM-NUTR}$), Hydrologic/Sediment Diversion ($\Delta C_{DOM-DIV}$), Restoration ($\Delta C_{DOM-RES}$) & Creation ($\Delta C_{DOM-CRE}$), Other Activities ($\Delta C_{DOM-OTHER}$)	Mangrove forest	Apply Eq. 2.18 and 2.20 or 2.19; Table 4.13
	Tidal marsh	$\Delta C = 0$
	Seagrass meadow	

Note – [1]Equations in this section can be found in the 2006 IPCC Guidelines; [2]EXT-D = physical removal of DOM pool associated with Extraction activity; EXT-I is not considered as it is only considered to have potentially significant impacts on seagrass meadows

4.2.2.1 CHOICE OF METHOD

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751 Changes in DOM resulting from management activities that occur in mangrove forests are estimated at the Tier 1
752 level because they represent potentially large CO_2 emissions to or removals from the atmosphere. Conversions
753 that result in loss of mangrove forest biomass or oxidation of soils can have large implications for CO_2 emissions
754 and removals. For tidal marsh and seagrass meadow, the default assumption is that no changes in C stocks occur
755 at the Tier 1 level of estimation. For significant management activities in mangrove forests and extensive
756 management activities that impact DOM pools in tidal marshes with perennial biomass, Tier 2 and higher
757 estimation methods should be used and these values reported. In these cases, stock changes should be
758 disaggregated relative to climate, vegetation type and salinity where applicable.

759 **TIER 1**

760 **Mangrove forest**

761 At Tier 1, for Aquaculture, Salt Production, and Extraction activities, it is assumed that C in DOM stocks is lost
762 as CO_2 emissions in the year of conversion and that no change in DOM C stocks occurs afterward. For these
763 activities, apply either *Gain-Loss* or *Stock-Difference* methods, following Chapter 2, Eq. 2.18 or 2.19 from
764 Volume 4, *2006 IPCC Guidelines*. If applying *Gail-Loss*, apply Eq. 2.18. If applying *Stock-Difference*, apply Eq.
765 2.19. However, at the start of the activity (construction phase, including extraction), instead of applying Eq. 2.20
766 to estimate DOM_{in} of Eq. 2.18, $DOM_{in} = 0$. For *Stock-Difference*, $DOM_{t2} = 0$. In years subsequent to the start of
767 the activity, the Tier 1 assumption is no change in DOM stock.

768 **Tidal marsh and Seagrass meadow**

769 For all management activities, the Tier 1 assumption is no change in DOM stock.

770 **TIERS 2 AND 3**

771 Tier 2 methodologies also employ Equations 2.18 or 2.19. However, country-specific data are encouraged,
772 especially where management activities are expected to have significant impacts on CO_2 emissions and removals.
773 For instance, after a management activity that results in a significant change in aboveground biomass stocks,
774 conversion of aboveground biomass to DOM as litter can be significant. Countries should use in such cases

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775 national estimates for litter stocks for mangrove forests and tidal marshes disaggregated by tidal regime, where
776 applicable. Loss estimates of dead wood and litter exports due to tidal advection should also be considered (see
777 Annex 1 regarding C exports). Tier 3 methods may further employ stratification by ecological zone or
778 disturbance regime to reduce uncertainties. Field measurements can further inform and be used to validate model
779 output at Tier 3. For mangroves, Tier 3 methodologies should employ empirical measurements of canopy litter
780 fall and census of downed wood lying on the forest floor. This methodology should involve the establishment of
781 replicate forest plots of at least 5 X 5 m area with monthly census taking of changes in wood and measurement
782 of litter lying within 1 X 1 m traps placed below the canopy but above highest astronomical tide (see Saenger
783 and Snedakar, 1993, for full description of these methods).

784 ## 4.2.2.2 CHOICE OF EMISSION/REMOVAL FACTORS

785 ## TIER 1

786 ### Mangrove forest

787 Countries using a Tier 1 method require data on the default dead wood and litter carbon stocks as defined in
788 Table 4.13. For coastal wetlands that are identified as mangrove forests prior to when the activity took place and
789 activities including aquaculture, salt production, extraction or hydrologic/sediment diversion occur, Tier 1
790 emission factors for DOM stocks should be used (Table 4.13). The Tier 1 assumption is that carbon stocks in
791 litter and dead wood pools in all non-forested coastal wetlands and in coastal wetlands where activities including
792 nutrient enrichment and harvesting of aquatic resources occur are zero.

793 ### Tidal marsh and Seagrass meadow

794 For all management activities, the Tier 1 emission factor for DOM stock change is zero.

795 ## TIER 2

796 The higher Tier methods described in Chapter 4 for Forest Land and Chapters 5 and 6 on Cropland and
797 Grassland of Volume 4 of the *2006 IPCC Guidelines* will permit better estimates when national data are applied.
798 Additional requirements may arise if the assumption that carbon stocks in dead wood or litter pools of tidal
799 marsh are zero cannot be justified, such as where intensive management activities have occurred.

800 ## TIER 3

801 Tier 3 emission factors include model output and validation and disaggregated data sources.

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TABLE 4.13 TIER 1 DEFAULT VALUES FOR LITTER AND DEAD WOOD CARBON STOCKS			
Domain	Ecosystem type	Litter carbon stocks of mature forests (tonnes C ha^{-1}) with 95% CI	Dead wood carbon stocks of mature forests (tonnes C ha^{-1}) with 95% CI
Tropical/Subtropical	Mangrove forest	0.7 (0-1.3)	10.7 (6.5-14.8)
Source: Litter: Utrera-Lopez and Moreno-Casasola 2008, Liao et al 1990, Chen et al 2008, Richards et al 2011, Ramose-Silva et al 2007, Twilley et al 1986 Dead Wood: Kauffman et al 2011, Donato et al 2012, Allen et al 2000, Steinke et al 1995, Robertson et al 1989, Tam et al 1995, Krauss et al 2005			

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804 ## 4.2.2.3 CHOICE OF ACTIVITY DATA

805 Choice of activity data follows from guidance provided in the *2006 IPCC Guidelines* in the Forest Land chapter
806 (p. 4.38). Also, refer to Section 4.2.1.3 for guidance relative to specific management activities.

807 **4.2.2.4   CALCULATION STEPS FOR TIER 1**

808   Calculations steps for Tier 1is presented in the *2006 IPCC Guidelines* and follows from guidance provided in the
809   Forest Land chapter (p. 4.38).

810 **4.2.2.5   UNCERTAINTY ASSESSMENT**

811   Guidance on uncertainty assessment for dead organic matter pools is unchanged from the *2006 IPCC Guidelines*
812   in the Forest Land chapter (p. 4.38). With specific regard to coastal wetlands, uncertainties follow from Tier 1
813   assumptions about tidal export of C as well as assumptions of only non-woody biomass in tidal marshes.

814 ## 4.2.3   Soil Carbon

815   Activities that occur within coastal wetlands can influence organic and mineral stocks of C in soils. The
816   methodological approach follows equation 4.1 which combines the emissions from the activities listed in Table
817   4.14. Current data on inorganic soil C are not sufficient to provide generic methodologies and so the
818   methodological approach provided here only takes into account the possible emissions and removals associated
819   with changes in organic C of organic and mineral soils.

820   Management activities that include extraction of saturated soils that are then deposited above the existing water
821   table, or that lead to drainage due to lowering of the water table, result in enhanced soil oxidation. The
822   management activities Aquaculture, Salt Production, Extraction and Drainage result in the most significant
823   effects on the soil carbon pool. These management activities however do not necessarily result in a land-use
824   category change and this consideration needs to be applied when reporting CO_2 emissions. Conversely,
825   restoration or creation of coastal wetlands can result in increased net C accumulation and subsequently net
826   removals of CO_2 from the atmosphere. These activities can also be significant.

827   Activities associated with either localised or extensive lowering of the water table are often associated with the
828   construction of drainage channels leading to CO_2 fluxes due to oxidation of dissolved organic and particulate
829   organic carbon in the water carried by drainage channels. However, there is currently not enough information to
830   provide emission factors for C exports (see Future Methodological Development).

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Table 4.14 Management Activities, Tier 1 Approaches and Tier 1 Equations for Soil Carbon Pool Changes

Activity	Ecosystem	Tier 1 Equation and Default EF
Aquaculture ($\Delta C_{SO\text{-}AQ}$), Salt Production ($\Delta C_{SO\text{-}SP}$)	Mangrove forest	**AQ, SP:** Apply Eq. 4.2. EF in Tables 4.15-4.18, this section **SP:** only *construction* and *abandonment* phases are considered
	Tidal marsh	
	Seagrass meadow	**AQ:** Only *use* phase is considered. Apply Eq. 2.6[1]; Table 4.17, this section,
Extraction ($\Delta C_{SO\text{-}EXT}$)	Mangrove forest	**EXT-D:** $\Delta C_{SO\text{-}EXT} = A_e * EF_{CONST,e} * P$ from Eq. 4.2. EF in Tables 4.15 & 4.16, this section
	Tidal marsh	
	Seagrass meadow	If **EXT-D**, $\Delta C_{SO\text{-}EXT} = A_{c,e} * EF_{CONST,e} * P$, Eq. 4.2, Table 4.17, this section; if **EXT-I** $\Delta C = 0$
Harvesting of Aquatic Resources ($\Delta C_{SO\text{-}HARV}$)	Mangrove forest	Apply Eq. 2.6[1]; Table 4.18, this section
	Tidal marsh	$\Delta C = 0$
	Seagrass meadow	
Nutrient Enrichment ($\Delta C_{SO\text{-}NUTR}$)	Mangrove forest	NA[2]
	Tidal marsh	
	Seagrass meadow	Apply Eq. 2.6[1]; Table 4.19, this section
Hydrologic/Sediment Diversion ($\Delta C_{SO\text{-}DIV}$)	Mangrove forest	$\Delta C = 0$
	Tidal marsh	
	Seagrass meadow	NA
Drainage ($\Delta C_{SO\text{-}DR}$)	Mangrove forest	Apply Eq. 4.3; Table 4.20, this section
	Tidal marsh	
	Seagrass meadow	NA
Restoration ($\Delta C_{SO\text{-}RES}$) & Creation ($\Delta C_{SO\text{-}CRE}$)	Mangrove forest	Apply Eq. 4.4; Table 4.21, this section
	Tidal marsh	
	Seagrass meadow	
Other Activities ($\Delta C_{SO\text{-}OTHER}$)	Mangrove forest	Apply Eq. 2.6[1]
	Tidal marsh	
	Seagrass meadow	

Note [1]Volume 4 of the *2006 IPCC Guidelines*
[2]no available Tier 1 guidance

4.2.3.1   AQUACULTURE, SALT PRODUCTION AND EXTRACTION

848 In aquaculture and salt production, the activity is broken down into three phases — *construction, use* and
849 *abandonment* — and emission factors are provided for each of these phases. Extraction effects can take two
850 forms: 1) direct via on-site physical removal of soil (EXT-D) or 2) specifically in seagrass meadows, indirectly
851 via effects of soil deposition and loss of water clarity (EXT-I)

852 *Construction* **phase and Extraction**

853   In excavation there is only one phase, which is equivalent to the *construction* phase of aquaculture and salt
854   production. During the *construction* phase of shrimp or fish ponds, or for salt production in mangrove forest and
855   tidal marsh ecosystems, soil is excavated to build containing berms within which water is held. Depending on the
856   type of aquaculture (intensive, extensive etc.) and the species stocked in the ponds (shrimp, fish) the soils can be
857   excavated to make ponds of 50 cm to 2.5 m depth (Cruz, 1997; Kungvankij et al. 1986; Wang 1990; Robertson
858   and Phillips 1995). In a similar manner the depth of solar salterns varies between depths of about 0.5 to 2.5m
859   (e.g. Ortiz-Milan 2006, Madkour & Gaballah 2012). Therefore at Tier 1, it is assumed that soil is excavated to 1
860   m depth and that this is appropriate for aquaculture and salt production in the *construction* phase, as well as
861   extraction. It is assumed that the soil excavated at the year in which these activities start is instantaneously
862   oxidized. Differentiation between organic and mineral soils should also be made when reporting on the
863   *construction* phase of aquaculture and salt production activities and extraction in mangrove forests and tidal
864   marshes. Available data suggest that only direct extraction will impact the soil C pool of seagrass meadows
865   through physical disturbance. Aquaculture in seagrass meadows using fish cages and pens is known to be a
866   significant activity in some coastal areas but requires no soil excavation.

867   ### *Use* phase

868   In the second or *use* phase of aquaculture and salt production, ponds, pens or cages are stocked or ponds
869   maintained for salt production. In aquaculture, the *use* phase results in CO_2 emissions from nutrient enrichment
870   of the soils due to feeding and growing of stock (Holmer et al. 2003; 2004). For aquaculture, there is currently
871   not enough information to provide emission factors for the *use* phase in tidal marshes and it is assumed that the
872   emission factor is the same as that for, *use*, in mangrove forests. Once aquaculture begins, it is assumed that
873   emissions persist until the ponds (constructed in mangrove forests and tidal marshes) or cages (established in
874   seagrass meadows) are abandoned. The average lifetime of a shrimp pond is variable depending on various
875   factors (management, water quality, and sediment characteristics) and a viability of 7–15 years has been
876   estimated, considering improved management (Flaherty and Karnjakesom 1995, Pa'ez-Osuna 2001). Thus an
877   average lifetime of 10 years is assumed before the activity ends. During the *use* phase, no differentiation is made
878   between organic and mineral soils. For salt production, there is currently not enough information to provide
879   emission factors for the *use* phase.

880   ### *Abandonment* phase

881   The final phase of aquaculture and salt production is the *abandonment* of the ponds, pens, or cage. In aquaculture
882   the ponds are usually abandoned due to disease or declining water quality (Stevenson et al 1999). During this
883   phase, the area utilized for aquaculture or salt production is assumed to leave the soils in a saturated condition.
884   For abandoned ponds maintained as saturated soils in mangrove forests the emissions are assumed to be the same
885   as for forest clearance until which time vegetation reestablishment begins. On abandonment, the area utilized for
886   aquaculture is generally left unchanged and the ponds can remain unproductive for decades, but sometimes
887   restoration of the local hydrology eventually leads to revegetation. In the *abandonment* phase, solar salterns
888   established in tidal marshes or fish pens and cages constructed in seagrass meadows, there is currently not
889   enough information to provide emission factors for these ecosystem types.

890   For aquaculture and salt production, the total change in C stocks in organic and mineral soils is estimated using
891   Equation 4.2 below, which combines emissions from soil organic matter decomposition during all phases. Direct
892   extraction of soil (EXT-D) is applied as for the construction term. In seagrass meadows there is the indirect
893   impact of extraction (EXT-I), which affects the soil C pools differently.

894 | |
895 | **EQUATION 4.2** |
896 | **ANNUAL CHANGE IN SOIL C IN COASTAL WETLANDS WITH AQUACULTURE, SALT PRODUCTION ACTIVITIES IN THREE PHASES OF SUB-ACTIVITIES AND EXTRACTION** |
897 | $CO_{2\text{-SO}}a,e = \Sigma\, e(A_{CONSTR},e * P * EF_{CONSTR},e) + (A_{USE},e * EF_{USE},e) + (A_{ABAN},e * EF_{ABAN},e)]$ |

898   where:

899   CO_{2SOe} = CO_2 emissions from either organic or mineral soils that are used in Aquaculture or Salt
900   Production occurring in the three phases of *construction, use* and *abandonment* or during Extraction and
901   ecosystem type(e) (mangrove forest, tidal marsh and seagrass meadow), unit = tonnes C yr^{-1}

902   A_e = Total area under aquaculture and salt production activities during the *construction, use and*
903   *abandonment* phases (for mangrove forests or tidal marshes), during *use* phase (for seagrass meadows) or

904   during extraction (for mangrove forests, tidal marshes or seagrass meadows) by ecosystem type (e) as
905   specified, unit = ha

906    $EF_{CONSTRe}$ = CO_2 emissions from either organic or mineral soils that are excavated for aquaculture or salt
907   production during the *construction* phase (for mangrove forests or tidal marshes) or during extraction (for
908   mangrove forests, tidal marshes or seagrass meadows) by ecosystem type (e) as specified, unit = tonnes C
909   ha^{-1}

910   P = fraction of area excavated for aquaculture or salt production during the *construction* phase. The same
911   value of P is used during the subsequent phases of *use* and *abandonment*. Tier 1 assumes P=1 for
912   aquaculture or Salt Production, or during *use* phase (for seagrass meadows), dimensionless.

913   EF_{USEe} = CO_2 emissions from aquaculture or salt ponds in mangrove forests and tidal marshes or covered
914   by aquaculture cages or pens in seagrass meadows by ecosystem type (e) as specified, unit = tonnes C ha^{-1}
915   yr^{-1}

916   EF_{ABANDe} = CO_2 emissions from saturated soils after abandonment of aquaculture or salt production
917   practices in mangrove forests as specified, unit = tonnes C ha^{-1} yr^{-1}

918   a = activity (aquaculture, salt production; extraction method is based on equation provided)

919   e = ecosystem type (specified ecosystem in which the activity has potentially significant impacts in
920   mangrove forest, tidal marsh, or seagrass meadow)

921

CHOICE OF METHOD - ORGANIC AND MINERAL SOILS

Tier 1

Mangroves and Tidal Marsh

925   The method for estimating changes in soil carbon for Tier 1 uses Equation 4.2 for CO_2 emissions from organic
926   and mineral soils. For Tier 1, extraction (EXT-D) is applied in the case of physical removal and CO_2 emissions
927   are reported for either or both ecosystems where this activity occurs. For salt production, emissions are only
928   reported for *construction* (mangrove forest and tidal marsh; Tables 4.15 & 4.16)) and *abandonment* (mangrove;
929   Table 4.18). For aquaculture, CO_2 emissions in mangroves and tidal marshes are reported for all three phases,
930   *construction*, *use* and *abandonment* following Equation 4.2. Data pertaining to CO_2 emissions from abandoned
931   aquaculture ponds on tidal marshes were not found and so the Tier 1 CO_2 emissions are assumed to be zero. It is
932   assumed that after 10 years the emissions associated with aquaculture *use* cease as the practise is abandoned.

933   At Tier 1, the area affected during use and abandonment must remain the same as that during the construction
934   phase and it is assumed that the entire area is affected (P=1).

Seagrass Meadow

936   For Tier 1, if extraction (direct extraction, EXT-D) is an important management activity, CO_2 emissions are
937   reported. For Tier 1 indirect effects of extraction (EXT-I), the default assumption is that no changes in C stocks
938   occur. For significant aquaculture activities in seagrass meadows, emissions are only reported for the *use* phase.
939   It is assumed that after 10 years the emissions associated with aquaculture *use* cease as the practise is abandoned
940   (Holmer et al., 2003).

Tier 2

942   During the phases of *construction*, *use*, and *abandonment* of aquaculture and salt ponds or aquaculture cages and
943   pens, the area in which the activities primarily occur may be better approximated as a proportion of the total area
944   identified for Tier 1 estimation. That is, higher Tier methods may define the area of the activity as the area of soil
945   actually excavated to construct the pond or covered by fish pens (i.e. P<1). For significant activities, Tier 2 and
946   higher estimation methods should be used and these values reported. In these cases emissions should be
947   separated relative to climate, ecological zone and salinity where applicable.

948   At Tier 2 countries should use national data on their particular aquaculture practices to include more specific
949   information on, depth of pond excavated during the construction phase and determine how type of stock and
950   feeding regime during the *use* phase affect CO_2 emissions and removals. Disaggregation of mineral and organic
951   soils during *abandonment*, and consideration of more appropriate differentiation with respect to salinity and
952   climate regime are some higher Tier improvements. For salt production, a Tier 2 level method requires more
953   specific information on depth of pond excavated. For extraction the method countries should use national data to

954   determine their particular extraction processes and the volume of soil removed as well as taking into account the
955   fate of the excavated soil.

956   **Tier 3**
957   Tier 3 methods can employ models to estimate CO_2 emissions based on the whether the practise involves
958   extensive or intensive farming techniques, the species farmed, stocking density and feeding regime, all of which
959   affect CO_2 emissions during *use* and likely *abandonment* phases. The effect of temperature and salinity on
960   benthic metabolism both seasonally and with climate and ecological zone should also be included. Tier 3
961   methods using models should be validated with field measurements. In salt production, the CO_2 emissions and
962   removals associated with the use phase would be improved by providing data to quantify these fluxes and how
963   the magnitude of the fluxes vary with the salt pond management practices.

964   **CHOICE OF EMISSION FACTORS - ORGANIC AND MINERAL SOILS**

965   **Tier 1**

966   *Mangrove forest, Tidal Marsh and Seagrass Meadow*
967   Default Tier 1 emission factors for aquaculture, salt production and extraction in organic and mineral soils are
968   given in Tables 4.54-4.18 and where appropriate, for each phase of the activity, as well as ecosystems affected.
969   These values should be used in conjunction with Equation 4.2 to estimate emissions. Land area must remain the
970   same through all three processes.

971

TABLE 4.15 EMISSION FACTORS (EF) ASSOCIATED WITH CONSTRUCTION (EF_{CONSTR}) OF AQUACULTURE (AQ), SALT PRODUCTION (SP) AND EXTRACTION (EXT) ON ORGANIC SOILS (TONNES C HA^{-1}) AT START OF ACTIVITY

Ecosystem	EF_{CONSTR}	95% CI	range	n
Mangrove forests	471[1]	454, 490	216 – 727.1	43
Tidal marsh	340[2]	328, 352	221 – 579	35
Seagrass meadow	NA			

[1] Adame et al. (2012), Breithaupt et al. 2012, Chmura et al. 2003, Donato et al. 2011, Kauffman et al. 2011, Osborne et al. 2011, Vegas-Vilarrúbia et al. 2010 .

[2] Anisfeld et al. 1999, Callaway et al. 1996, Callaway et al. 2012, Chmura & Hung 2004, Craft et al. 1988, Craft 2007, Hussein et al. 2004, Kearney & Stevenson 1991, Orson et al. 1998, Markewich et al. 1998, McCaffrey & Thomson 1980.

972

973

TABLE 4.16 EMISSION FACTORS (EF) ASSOCIATED WITH CONSTRUCTION (EF_{CONSTR}) OF AQUACULTURE (AQ), SALT PRODUCTION (SP) AND EXTRACTION (EXT) ON MINERAL SOILS (TONNES C HA^{-1}) AT START OF ACTIVITY

Ecosystem	EF_{CONSTR}	95% CI	range	n
Mangrove forests	286[1]	266, 306	80 - 1376	77
Tidal marshes	226[2]	214, 239	15.6 – 623	82
Seagrass meadow[3]	140[4]		9.1 – 829	89

[1] Donato et al. 2011, Chmura et al. 2003, Breithaupt et al. 2012, Fujimoto et al. 1999, Adame et al. 2012, Perry & Mendelssohn 2009, Ren et al. 2010, Kauffman et al. 2011, Ray et al. 2011, Zhang et al. 2012, Khan et al. 2007, Matsui 1998.

[2] Cahoon et al. 1996, Callaway et al. 2012, Chmura & Hung 2004, Connor et al. 2001, Craft et al. 1988, Craft 2007, Hatton 1981, Kearney & Stevenson 1991, Livesley & Andrusiak 2012, Loomis & Craft 2010, Morris & Jensen 2003, Oenema & DeLaune 1988, Patrick & DeLaune 1990, Roman et al. 1997, Yu & Chmura 2009.

[3]For EXTRACTION (EXT) only; [4] Fourqurean et al 2012

974

TABLE 4.17 ANNUAL EMISSION FACTORS (EF) ASSOCIATED WITH USE (EF$_{USE}$) OF AQUACULTURE (AQ) ON ORGANIC AND MINERAL SOILS (TONNES C HA^{-1} YR^{-1})

Ecosystem	EF$_{USE}$	95% CI	range	n
Mangrove forests and Tidal marshes	2.2[1,2]	1.7, 2.7	0.34-5.9	15
Seagrass meadow	9.5[3]	7.8, 11.6	1.4-28.8	22

[1] Alongi 1999b, Alongi et al. 2004, Blackburn et al. 1988, Lovelock et al. 2011;

[2] It is assumed that EF for tidal marsh is the same as that for mangrove forests.

[3] Holmer et al. 2003, Holmer et al. 2005, Heilskov & Holmer 2001

975

TABLE 4.18 ANNUAL EMISSION FACTORS (EF) ASSOCIATED WITH ABANDONMENT AFTER AQUACULTURE (AQ) OR SALT PRODUCTION (SP) UNDER SATURATED CONDITIONS (EF$_{ABAN-S}$) ON ORGANIC AND MINERAL SOILS AND HARVESTING OF AQUATIC RESOURCES (EFHARV) IN MANGROVE FORESTS (TONNES C HA^{-1} YR^{-1})

Ecosystem	EF$_{ABAN-S}$/EF$_{HARV}$	95% CI	Range	N
Mangrove forests	1.8[1]	0.9, 3.5	0.40 – 7.9	4

[1] Alongi et al. (1998), Lovelock et al. (2011), Cahoon et al. (2003). Data from forest clearance assumed to be the same as Aquaculture during the *abandonment* phase.

976

Tier 2

977
978 Tier 2 could include the use of country specific emission factors for each ecosystem that take into account local
979 climatic factors. For fish and shrimp ponds, the actual area excavated (P<1) and depth to which soil is excavated,
980 should be taken into account as this varies with aquaculture and salt production practices. During the phase, *use*,
981 and the phase, *abandonment* in mangrove forests, the EF could be disaggregated to provide separate values for
982 organic and mineral soils. Furthermore, country-specific data would include emission factors for tidal marshes
983 and seagrass meadows in the *abandonment* phase.

Tier 3

984
985 A Tier 3 approach could use models that take into account the time-dependent nature of the CO_2 fluxes over a
986 range of timescales. For example, during the construction phase a pulse of CO_2 efflux from soil directly after
987 mangrove clearing and prior to excavation, followed by a logarithmic decline in CO_2 fluxes over time should be
988 considered.

4.2.3.2   HARVESTING OF AQUATIC RESOURCES

989

990 Guidance on annual change in soil carbon stocks on coastal wetlands managed for resource harvest is provided
991 only in the case of deforestation or complete clearing of aboveground biomass in mangrove forests. These
992 emissions result in net CO_2 flux to the water or atmosphere as there are assumed to be no C inputs to soil once
993 aboveground biomass has been removed. It is assumed that mangrove wood harvesting does not affect the height
994 of the water table and that the soils remain saturated.

995 Selective logging in mangrove forests, harvesting of vegetation in tidal marshes or shellfish in seagrass meadows,
996 are likely to have a low impact on carbon soil stocks and so the Tier 1 C stock change is assumed to be zero. If
997 any of these activities contribute to emissions that represent a key category, then Tier 2 or Tier 3 estimation
998 methodologies are recommended.

CHOICE OF METHOD & EMISSION/REMOVAL FACTORS

999

Tier 1

1000

Mangrove forest

1001
1002 Default Tier 1 emission factor for harvesting of mangrove wood, resulting in forest clearance, is presented in
1003 Table 4.17. For harvesting of aquatic resources, the methodology follows Eq.4.2, however only the *abandonment*
1004 term is reported.

1005 **Tier 2**

1006 Tier 2 methods for wood harvesting may take into consideration the species of mangrove being felled and
1007 determination of country specific emission factors to disaggregate between organic and mineral soils. It may be
1008 possible to disaggregate emission factors for tree clearance and selective logging. At Tier 2, country and
1009 ecosystem specific emission factors may be also used to reflect the regional importance of harvesting specific
1010 resources.

1011 **Tier 3**

1012 A Tier 3 approach requires a comprehensive understanding of the processes that lead to CO_2 emissions and
1013 removals and the factors that drive these fluxes. The Tier 3 approach will involve country-specific models and/or
1014 measurement-based approaches along with disaggregated land-use data to incorporate information on the type of
1015 resources being harvested, the nature of the disruption to the soil, tidal regime, and local salinity. Tier 3
1016 modelling would include country-specific emission factors derived or modelled from measurement data
1017 encompassing different resource harvesting and the physical methods deployed. The models should capture
1018 variation in emission rates driven by soil disruption, seasonal changes in precipitation and temperature and tidal
1019 influence.

1020 ## 4.2.3.3 NUTRIENT ENRICHMENT

1021 Guidance on annual change in emissions associated with nutrient enrichment is provided only in the case of
1022 mangrove forests and seagrass meadows. Note that data for tidal marshes is insufficient to generate an emission
1023 factor for nutrient enrichment and so it is assumed that the emission factor is the same as reported for mangrove
1024 forests.

1025 ### CHOICE OF METHOD AND EMISSION FACTOR

1026 **Tier 1**

1027 Mineral and organic soils have been aggregated for default Tier 1 emission factors for Nutrient Enrichment in
1028 seagrass meadows and are presented in Table 4.19. The emissions should be quantified by applying Eq. 2.6, Vol.
1029 4 and be used in conjunction with equation 4.2.

TABLE 4.19 ANNUAL EMISSION FACTORS (EF) ASSOCIATED WITH NUTRIENT ENRICHMENT (EF_{NUTR}) ON ORGANIC AND MINERAL SOILS (TONNES C HA^{-1} YR^{-1})

	EF_{NUTR}	95% CI	Range	N
Seagrass Meadow	3.5[1]	2.7, 4.5	1.9 - 7.2	5

[1]Holmer et al. 2005, Heilskov et al. 2008; No data available for tidal marshes.

1030

1031 **Tier 2 and 3**

1032 A Tier 2 approach will involve country-specific emission factors and may take into consideration the source of
1033 the nutrient enrichment and their regional importance. Disaggregation of mineral and organic soils should be
1034 considered. A Tier 3 approach will use measurement-based approaches along with disaggregated land-use data
1035 to incorporate data on variable rates that will better capture variation in emission rates associated nutrient
1036 application or discharge rate as well as factors that include consideration of diel fluctuations in temperature, tidal
1037 regime, and salinity. If this activity contributes to emissions that contribute to a category that is key, then Tier 2
1038 or Tier 3 estimation methodologies are recommended. If nutrient enrichment is a significant activity constituting
1039 managed coastal wetlands in tidal marshes and mangrove forests, Tier 2 or 3 estimation methodologies are also
1040 recommended.

1041 ## 4.2.3.4 HYDROLOGIC/SEDIMENT DIVERSION

1042 Annual change in carbon stocks on coastal wetland managed for hydrologic and sediment diversion can occur in
1043 mangrove and tidal marsh. The Tier 1 emission factors for soils in all ecosystems as a result of coastal

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1044 subsidence are also considered to be zero. If this activity contributes to emissions that contribute to a category
1045 that is key, then Tier 2 or Tier 3 estimation methodologies are recommended.

1046 ## 4.2.3.5 DRAINAGE

1047 Emissions from drained coastal wetland soils are estimated at Tier 1 for mangrove forests and tidal marshes
1048 because they represent potentially large CO_2 emissions to the atmosphere. Annual C losses from both drained
1049 mineral and organic soils in mangrove forests and tidal marshes are aggregated at Tier 1 level of estimation
1050 using Equation 4.3.

1051
1052
1053

> **EQUATION 4.3**
> **ANNUAL CHANGE IN CARBON STOCKS IN DRAINED ORGANIC AND MINERAL SOILS**
> $$CO_{2DR} = \sum_e (A_e \bullet EF_e . F_{PD})$$

1054 where:

1055 CO_{2DR} = CO_2 emissions from organic or mineral soil C through drainage, units = tonnes C yr^{-1}

1056 A = land area under drainage, units = ha

1057 $EF_{DR,e}$ = CO_2 emissions from organic or mineral soil C through drainage ecosystem type (e), units =
1058 tonnes C ha^{-1} yr^{-1}

1059 F_{PD} = fraction of area that is partially drained. Tier 1 assumes $F_{PD}=1$

1060

TABLE 4.20 ANNUAL EMISSION FACTORS (EF) ASSOCIATED DRAINAGE (EF_{DR}) ON ORGANIC AND MINERAL SOILS (TONNES C HA^{-1} YR^{-1})

Ecosystem	EF_{DR}	95% CI	Range	N
Mangrove forests and tidal marshes	$7.9^{1,2}$	6.5, 9.6	1.2 – 43.9	22

[1] Camporese et al. (2008), Deverel & Leighton (2010), Hatala et al. (2012), Howe et al. (2009), Rojstaczer & Deverel (1993).

[2] Based on aggregated data from tidal marshes and mangrove forests.

1061

1062 ## CHOICE OF METHOD AND EMISSION/REMOVAL FACTORS

1063 ### Tier 1 – Organic and Mineral Soils

1064 #### *Mangrove forest and Tidal Marsh*
1065 The default Tier 1 assumption for drainage is that organic C is lost linearly over time until the stock is fully
1066 oxidised to CO_2, further drainage is initiated, or a new land use has started. Our default assumption is that the
1067 water table has been changed to 1 m below the soil surface for organic and mineral soils. If drainage does not
1068 result in a land-use change, the inventory compiler is referred to the aggregated emission factor for drained
1069 organic and mineral soils in tidal marshes and mangrove forests as reported in Table 4.20.

1070 If drainage results in conversion to a new Land Use category, the inventory compiler is referred to Section 4.3 of
1071 this Chapter It is important under these reporting conditions to retain information about the conversion so that
1072 wetlands guidance can be applied if a reversal of drainage conditions occurs.

1073 ### Tier 2 and Tier 3

1074 The Tier 2 approach should incorporate country specific data on emission for soils disaggregated for mineral and
1075 organic soils. Higher Tier methods could take account of differences in the management of the drained coastal
1076 wetland, drainage and the fraction of area that is partially drained (F_{PD}) should be determined.

1077 ## 4.2.3.6   RESTORATION AND CREATION

1078   Rewetting saturates the soil, which can lead to colonization by new wetland vegetation, that is, the subsequent
1079   natural re-establishment of original vegetation type in mangrove or tidal marsh ecosystems. Alternatively,
1080   rewetting of the soil can be followed by active replanting that restores the original vegetation type. In seagrass
1081   meadows, soils remain saturated and it is the water quality that must reach a satisfactory level before re-
1082   establishment of vegetation or its restoration. The original ecosystem can be either re-established naturally, or by
1083   manual replanting. Under these conditions, where vegetation becomes re-established, ecosystem restoration or
1084   creation is assumed to occur. Creation occurs where coastal wetlands cannot be verified to have previously
1085   occurred but likely occurred given the proximity of the land to the coastal margin. Rehabiliation, a form of
1086   creation where the re-establishment of any vegetation type results in soil C sequestration upon maturation
1087   (defined as 20 year since establishment).

1088   Guidance for inventories of rewetting and restoration of coastal wetland ecosystems follows several general
1089   simplifying assumptions at Tier 1 level of estimation of CO_2 emissions from soil:

1090   1.   upon rewetting of previously drained soil, or re-establishment of water quality, creation of biomass by
1091   purposeful planting or restoration of biomass is initiated. During this 20 year transient period it is assumed
1092   that soil emissions and removals are insignificant, so that rewetting of coastal wetlands results in a Tier 1 EF
1093   = 0

1094   2.   after the 20 year transient period, restoration results in a change to a coastal wetland ecosystem supporting
1095   growth of mangrove, tidal marsh or seagrass biomass, which can then accumulate soil C whereby a Tier 1
1096   soil EF_{RES} is applied. At this time it is assumed that soil C accumulation rates are functionally equivalent to
1097   the natural system net soil C accumulation (flux) and the Tier 1 EF_{RES} is applied (Table 4.20) with the same
1098   EF applied regardless of soil type (Craft et al 2003, McGlathery et al 2012, Osland et al 2012).

1099   If the re-establishment of functioning vegetation is demonstrated to be unsuccessful during rewetting an, EF=0 is
1100   applied for a further 20 year period or until creation or restoration of biomass occurs. For creation it is assumed
1101   that once the site has been purposefully planted the EF=0 for soil for a 20 year transient period, by which time
1102   functionally equivalent soil C accumulation rates are assumed to occur and EF_{CRE} can be applied. Therefore
1103 EF_{RES} is the same as EF_{CRE}

1104   **EQUATION 4.4 ANNUAL CHANGE IN SOIL C IN RESTORED AND CREATED COASTAL WETLANDS**
1105 $$CO_{2SO\text{-}RESe} = (A_{RESe} * EF_{RESe}) \qquad CO_{2SO\text{-}CREe} = (A_{CREe} * EF_{CREe})$$

1106   where,

1107 $CO_{2SO\text{-}RESe}$ = CO_2 emissions associated with rewetted, improved water quality and restored coastal
1108   wetlands by ecosystem type (mangrove, tidal marsh and seagrass meadow), units = tonnes C yr^{-1}

1109 $CO_{2SO\text{-}CREe}$ = CO_2 emissions associated with rewetted improved water quality and created coastal
1110   wetlands by ecosystem type (mangrove, tidal marsh and seagrass meadow), units = tonnes C yr^{-1}

1111 A_{RESe} = Area of soil that has been modified by rewetting, improved water quality and/or restoration, by
1112   ecosystem type (e), units = ha

1113 EF_{RESe} = CO_2 emissions from mineral and organic soils that have been modified by restoration, by
1114   ecosystem type (e), units = tonnes C ha^{-1} yr^{-1}

1115 A_{CREe} = Area of soil that has been modified by rewetting and/or creation, by ecosystem type (e), units =
1116   ha

1117 EF_{CREe} = CO_2 emissions from mineral and organic soils after creation by ecosystem type (e), units =
1118   tonnes C ha^{-1} yr^{-1}

1119   This method can be applied for lands with either mineral or organic soils. At Tier 1, organic and mineral soils are
1120   not differentiated and land area estimates should be based on vegetation classification within the new land
1121   category to apply Tier 1 EFs.

1122   ## CHOICE OF METHOD AND EMISSION/REMOVAL FACTORS

1123   ### Tier 1

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1124 *Mangrove, Tidal Marsh and Seagrass Meadow*
1125 Changes in soil carbon resulting from management activities that occur during rewetting and restoration or
1126 creation are estimated at Tier 1 level because they represent potentially large C removals from the atmosphere.
1127 During the transitional, rewetting period, the soil EF=0 regardless of the vegetation that is present. An EF=0 is
1128 applied until 20 years after vegetation re-establishment. The land can be assumed restored with functioning
1129 vegetation unless the definition of a classified vegetation type (as determined by country land classification
1130 system) is not met. Once the land enters the new land category, the EF in Table 4.21 can be applied. EF values
1131 should be used in conjunction with Equation 4.4 to estimate emissions.

1132

TABLE 4.21 ANNUAL EMISSION FACTORS (EF) ASSOCIATED WITH RESTORATION OR CREATION ($EF_{RES/CRE}$) ON ORGANIC AND MINERAL SOILS (TONNES C HA^{-1} YR^{-1}) AFTER 20 YEARS OF VEGETATION REESTABLISHMENT					
Ecosystem	$EF_{RES/CRE}$	95% CI		range	n
Mangrove	1.62[1]	0.73	3.63	0.10 – 10.2	69
Tidal marsh	0.91[2]	0.82	1.02	0.05 – 4.65	66
Seagrass meadow	0.43[3]	0.28	0.67	0.09 – 1.12	6

[1] Breithaupt et al. 2012, Chmura et al. 2003, Fujimoto et al. 1999, Ren et al. 2010.

[2] Anisfeld et al 1999, Cahoon et al. 1996, Callaway et al 1996, Callaway et al 1997, Callaway et al 1998, Callaway et al 1999, Callaway et al. 2012, Chmura & Hung 2003, Hatton 1981, Craft 2007, Kearney & Stevenson 1991, Markewich et al. 1998, Oenema & DeLaune 1988, Orson et al 1998, Patrick & DeLaune 1990, Roman et al 1997.

[3] Mateo & Romero 1997, Serrano et al. 2012.

1133

1134 ## Tier 2 and 3

1135 For key categories, Tier 2 and higher estimation methods should be used and these values reported. Soil types,
1136 organic and mineral, should be disaggregated in order to apply suitable country-specific factors. Country-specific
1137 emission factors applied during the rewetting of the lands and the transition period should be used under Tier 2
1138 methods, and the inventory compilers are encouraged to estimate the transient time from rewetted to restored
1139 wetlands. Under the tier 3 method, the land use prior to rewetting, climate and vegetation type should be taken
1140 into account. A comprehensive understanding and representation of the dynamics CO_2 gas emission factors,
1141 based on field measurement is involved in Tier 3. A Tier 3 approach would also use models that take into
1142 account the time-dependent nature of the CO_2 fluxes over a range of timescales and the effects of sea-level rise
1143 on soil C sequestration rates (Morris et al., 2012) or other dynamics (Craft 2001).

1144 ## 4.2.3.7 OTHER ACTIVITIES

1145 This category is retained to draw attention to the fact that all significant activities may not be covered in this
1146 guidance. It is good practice to consider other activities which may, based on national circumstances, have
1147 significant C emissions or removals associated with that management activity. A generic method is provided in
1148 Table 4.13.

1149 ## 4.2.3.8 CHOICE OF ACTIVITY DATA

1150 See guidance provided in Section 4.2.1.3.

1151 ## 4.2.3.9 CALCULATION STEPS FOR TIER 1

1152 The following summarizes steps for estimating change in carbon stocks in soils for Land Remaining in a Land-
1153 use Category where managed coastal wetlands occur.

1154 Step 1: Organize data into inventory time periods based on the years in which activity data were collected (e.g.,
1155 1990 and 1995, 1995 and 2000, etc.).

1156   Step 2: Determine the area of coastal wetland in the last year of the inventory time period.

1157   Step 3: Determine the activities to be included in the assessment and their representative areas. Area data should
1158   be obtained using the methods described in Chapter 3 of the *2006 IPCC Guidelines*.

1159   Step 4: Determine the activity categories by stratifying representative areas into soil type and previous coastal
1160   wetland vegetation type.

1161   Step 5: For each activity category, assign the appropriate emission factor (EF) for annual losses of CO_2.

1162   Step 6: Estimate total emissions by summing the product area (A) multiplied by the emission factor (EF) for all
1163   activity categories.

1164   Step 7: Repeat for additional inventory periods.

1165   **Example:** The following example shows the calculations for aggregate areas of soil carbon change in
1166   coastal wetlands. There is a 1Mha area of coastal wetlands. At the beginning of the inventory time period
1167   (1990 in this example) the total area of coastal wetlands was 500,000 ha. From this total 200,000 ha was
1168   identified as unmanaged and 300,000 ha was actively managed. The individual areas relevant to activities
1169   included in the inventory are; 50,000 ha of area under aquaculture with organic soils in previous
1170   mangrove forest (with 50%) under *construction* and 50% under *use*); 10,000 ha of area under aquaculture
1171   with mineral soils in previous tidal marsh (with 90% under *use* and 10% *abandoned*); 50,000 ha of area
1172   under fish cages in seagrass meadows (100% under *use*); 100,000 ha of area under salt production with
1173   mineral soils in previous tidal marsh (with 100% under *construction*); and 90,000 ha of area under
1174   hydrologic diversion. The CO2 emissions for the inventory time period are calculated as (50,000 ha • 0.5
1175   • 471 tonnes C ha^{-1}) + (50,000 ha • 0.5 • 2.2 tonnes C ha^{-1}) + (10,000 ha • 0.9 • 2.2 tonnes C ha^{-1}) +
1176   (10,000 ha • 0.1 • 7.9 tonnes C ha^{-1}) + (50,000 ha • 9.5 tonnes C ha^{-1}) + (100,000 ha • 340 tonnes C ha^{-1}) +
1177   (90,000 ha • 0 tonnes C ha^{-1}) = 46,332,700 tonnes C for 1990. Repeat for additional inventory periods.

1178   ## 4.2.3.10   UNCERTAINTY ASSESSMENT

1179   Few studies have addressed the questions of emission factors specifically and few reports are available to give
1180   specifics of activities which we expect to vary geographically. Thus, derivation of emission factors was based
1181   upon expert knowledge and application of data from reports of biomass and production of vegetation, the amount
1182   of carbon is living biomass and the amount of carbon held in soils, and how easily it is decomposed. There is
1183   uncertainty in the time, depth of soil affected, the rate of CO_2 loss from dead vegetation and soils and the C
1184   gained during wetland creation or restoration.

1185   ## 4.2.4   Non-CO_2 emissions

1186   This section provides methods for estimating the emissions of N_2O and CH_4 from coastal wetlands under
1187   different management activities.

1188 N_2O is an intermediate product of both nitrification (oxidation of ammonium by nitrifying microbes under oxic
1189   or aerobic conditions) and denitrification (reduction of nitrite and nitrate by denitrifying microbes under anoxic
1190   conditions). The flux of N_2O thus is controlled by oxygen availability and tidal influence, but also by the
1191   availability of N substrates (Purvaja and Ramesh, 2001; Kreuzwieser et al., 2003; van den Heuvel et al., 2009,
1192   Moseman-Valtierra et al. 2011). Therefore, management activities that change hydrology or N availability in
1193   sediment, e.g. N management or rewetting of wetlands, could lead to changes in N_2O emissions from coastal
1194   wetlands.

1195   In reduced and anoxic environments microbial decomposition of the organic matter may produce CH_4. However,
1196   flooding seawater contains sulfate and microbial reduction of sulfate to sulfide will generally occur before
1197   methanogens produce CH_4. A strong inverse relationship between CH_4 emission and salinity of mangrove soils
1198   was reported by Purvaja and Ramesh (2001) and later work by Poffenbarger et al. (2011) showed that polyhaline
1199   tidal marshes (salinity >18) had significantly lower CH_4 emissions than oligohaline (salinity 0.5-5) and
1200   mesohaline (salinity 5-18) marshes. The depth distribution of methanogenesis in tidal marsh soils is closely
1201   related to the methanogenic substrate utilization (Parkes et al. 2012).

1202 Aquaculture has been shown to lead to changes in N_2O emissions from coastal wetlands. Shrimp and fish
1203 cultivation increases nutrients loads in culture ponds. The body of research is growing, and sufficient for
1204 developing emission factors for non-CO_2 emissions from this activity but is relatively limited. Coastal wetlands
1205 subject to intensive carbon and nutrient loading may also be sources of CH_4 emissions, however, only when
1206 salinity <18 are present. In aquaculture, anaerobic conditions are not appropriate for maximized fish production
1207 and are therefore assumed negligible, however, they may increase over time.

1208 If soil conditions prior to rewetting were aerobic, then it is likely that CH_4 emissions will increase where tidal
1209 water salinities are <18 ppt. If tidal waters rewetting coastal wetlands are carbon- or nutrient-enriched, then
1210 wetlands with salinities >18 ppt also are likely to be sources of CH_4 emissions. One of the main controlling
1211 factors in N_2O production is the availability of inorganic N in the soil. If, prior to rewetting, the area of coastal
1212 wetland was subject to increased N supply (e.g. in fertilized land) it may be a source of N_2O emissions during
1213 the rewetting. However, experimental studies have shown that the substrate N is rapidly depleted (Moseman-
1214 Valtierra et al. 2011), thus N_2O is likely to be negligible after the N is depleted and no continuous N is supplied.

1215 N_2O emissions from managed terrestrial soils are covered in Chapter 11, Volume 4 of the *2006 IPCC Guidelines*,
1216 which estimates N_2O emissions due to N additions to soils (e.g. synthetic or organic fertilizers, deposited manure,
1217 crop residues, sewage sludge), or of mineralization of N in soil organic matter following management of organic
1218 soils or cultivation on mineral soils (e.g., Forest Land/Grassland/Settlements converted to Cropland). For organic
1219 soils, these emission factors have been updated for these specific land uses and can be found in Chapter 2 of this
1220 Supplement Table 4.21 presents the equations and emission factors for managed coastal wetland. The most
1221 significant activities contributing to non-CO_2 emissions from managed coastal wetlands are Aquaculture and
1222 specific cases of nutrient enrichment, such as aquaculture effluent (indirect N_2O emissions from aquaculture use)
1223 for which there are available data Non-CO_2 emissions are assumed equal to zero except in the cases of
1224 Aquaculture effects on N_2O emissions and nutrient enrichment effects on CH_4 emissions caused by aquaculture
1225 and agricultural run-off in coastal wetlands.

TABLE 4.22 ACTIVITIES AND TIER 1 ASSUMPTIONS FOR NON-CO_2 EMISSIONS FOR THE ECOSYSTEMS AFFECTED			
Activity	**Ecosystem**	**Non-CO_2 gas/sub-activity**	**Tier 1 Equation**
Aquaculture (EF_{AQ})[1]	Mangrove	CH_4: EF=0	NA
		N_2O: EF=based on fish production or N fed or nutrient-enriched EF	Apply Eq. 4.5; Table 4.23
	Tidal Marsh	CH_4: EF=0	NA
		N_2O: EF=based on fish production or N fed	Apply Eq. 4.5; Table 4.23
	Seagrass Meadow	CH_4: EF=0 N_2O: EF=0	NA
Salt Production (EF_{SP}), Extraction (EF_{EXT}), Hydrologic/Sediment Diversion (EF_{DIV}), Harvesting of Aquatic Resources (EF_{HARV}), Drainage (EF_{DR})	Mangrove	CH_4: EF=0 N_2O: EF=0	NA
	Tidal Marsh	CH_4: EF=0 N_2O: EF=0	
	Seagrass Meadow	NA	
Nutrient Enrichment (EF_{NUTR})	Mangrove	CH_4: EF=nutrient-enriched wetland (agricultural run-off including aquaculture effluent)	Apply Eq. 2.6[2]; table 4.24, this section
		N_2O: Run-off from terrestrial soil N application	Chapter 11[2]
		N_2O: Enrichment from aquaculture effluent	Apply Eq. 2.6[2]; table 4.25, this section

	Tidal Marsh	CH_4: EF=nutrient-enriched wetland (agricultural run-off including aquaculture effluent)	Apply Eq. 2.6[2]; table 4.24, this section
		N_2O: Run-off from terrestrial soil N application	Chapter 11[2]
		N_2O: Enrichment from aquaculture effluent	Apply Eq. 2.6[2]; table 4.25, this section
	Seagrass Meadow	CH_4: EF=0	NA
		N_2O: Run-off from terrestrial soil N application	Chapter 11[2]
		N_2O: Enrichment from aquaculture effluent	NA
Restoration (EF_{RES}) and Creation (EF_{CRE})	Mangrove	CH_4: EF=unmanaged wetland N_2O: EF=0	Apply Eq. 2.6[2]; table 4.26, this section
	Tidal Marsh	CH_4: EF=unmanaged wetland N_2O: EF=0	
	Seagrass Meadow	NA	NA
Other Activities (EF_{OTHER})	Mangrove	NA	NA
	Tidal Marsh		
	Seagrass Meadow		

Note

[1]for aquaculture, only the *use* phase is considered; EF for phases of *construction* and *abandonment* are assumed negligible

[2]Volume 4 of the *2006 IPCC Guidelines*

1226

4.2.4.1   AQUACULTURE

CHOICE OF METHOD AND EMISSION FACTORS

Seitzinger et al. (2000) estimated that one-third of global anthropogenic N_2O emissions are from aquatic ecosystems, but there has been limited research aimed at quantifying the contribution of aquaculture to the global budget. N_2O is emitted from aquaculture systems as a by-product of the conversion of ammonia (contained in fish urea) to nitrate through nitrification and nitrate to N_2 gas through denitrification (Hu et al. 2012). Hu et al. (2012) estimates that 1.8% of the nitrogen fed to aquaculture systems is emitted as N_2O, and that 1.7 g N_2O-N is emitted per kg fish produced in an aquaculture system. These are applied only during the *use* phase of aquaculture. In the *construction* and *abandonment* phases, non-CO_2 emissions are assumed negligible and EF=0.

Tier 1

Methane

The Tier 1 method estimates the CH_4 emissions from aquaculture ponds are assumed negligible and reported as 0.

Nitrous Oxide

N_2O emissions from aquaculture ponds can be estimated based on fish production or the amount of N feed in the aquaculture activity. The default Emission Factors for these two methods are provided in Table 4.23. The emission estimation follows a modified form of Eq. 11.1 from Chapter 11, Volume 4 of the *2006 IPCC Guidelines* and is presented here in (Eq. 4.5).

1244

1245

EQUATION 4.5

DIRECT N₂O EMISSIONS FROM AQUACULTURE USE

$$N_2O\text{-}N_{AQ} = F_F * EF_F \text{ OR } F_I * EF_I$$

1246
1247
1248

1249 Where:

1250 $N_2O\text{-}N_{AQ}$ = annual direct N_2O-N emissions from Aquaculture use, kg N_2O-N yr^{-1}

1251 F_F = annual fish production, kg fish yr^{-1}

1252 EF_F = emissions factor for N_2O emissions from fish produced, kg N_2O-N (kg fish produced)$^{-1}$

1253 F_I = annual N amount of fish feed applied

1254 EF_I = emission factor for N_2O emissions from N of fish feed applied, kg N_2O-N (kg N fed)$^{-1}$

1255

Table 4.23 Emission factors for N₂O emission from aquaculture in coastal wetlands			
Wetland	**Default EF**	**Uncertainty Range**	**Reference**
Aquaculture	0.003 kg N₂O per kg fish produced per yr		Hu et al. 2012
	0.028 kg N₂O per kg N fed per yr		

1256

1257 Tiers 2 and 3

1258 Under Tier 2 method, country specific emission factors for these two gases need to be applied. N_2O emissions
1259 from aquaculture ponds could also be estimated using the country specific emission rate from the water if such
1260 data is available. In terms of CH_4, Tier 2 or 3 methods could include change in CH4 emissions with extended use,
1261 based on age of the pond and intensity of use. A comprehensive understanding and representation of the
1262 dynamics based on direct field measurements or models is involved under Tier 3 method, which estimates
1263 emission factors considering the category of aquaculture (fish species or feed stuff), aquaculture use intensity,
1264 and impact of environmental factors e.g. climate zone, season, and salinity.

1265 4.2.4.2   SALT PRODUCTION, EXTRACTION,
1266   HYDROLOGIC/SEDIMENT DIVERSION, HARVESTING OF
1267   AQUATIC RESOURCES, DRAINAGE

1268 As was noted in Table 4.22, CH_4 and N_2O emissions from the management activities of salt production,
1269 extraction, hydrologic/sediment diversion and harvesting of aquatic resources are assumed to be zero. However,
1270 under higher Tiers, emissions associated with these activities should be reported using country-specific data.

1271 As was noted in Table 4.22, CH_4 and N_2O emissions from the management activities of drainage are assumed to
1272 be zero. However, if drainage is a significant activity within the Land Use category under which it is reported, it
1273 is good practice to apply Tier 2 and 3 estimation levels following generic methodologies (Eq. 2.6, *2006 IPCC*
1274 *Guidelines*) and using country-specific data.

1275 4.2.4.3   NUTRIENT ENRICHMENT

1276 CHOICE OF METHOD AND EMISSION/REMOVAL FACTORS

1277 Methane and Nitrous Oxide - Mangrove and Tidal Marshes

1278 Tier 1

1279 For the Tier 1 method, the default emission factors are given in Tables 4.24 and 4.25. The default method to
1280 estimate non-CO_2 gas emissions from coastal wetlands is to multiply wetland area by the gas emission rates. For
1281 nutrient enrichment from agricultural run-off in the coastal zone, only CH_4 emissions are reported. N_2O
1282 emissions for this activity are covered in Chapter 11 of the *2006 IPCC Guidelines*. For nutrient enrichment from
1283 aquaculture effluent coming from aquaculture production both CH_4 and N_2O emissions are reported as there is
1284 currently no guidance in *2006 IPCC Guidelines* on non-CO_2 emissions from this impact of aquaculture activities.
1285 Data were not available on impact of aquaculture effluent on seagrass meadows.

1286 Calculation of CH_4 emissions follows the same method applied in the case of agricultural run-off to the coastal
1287 zone and aquaculture effluent within the coastal zone (Table 4.24). For calculation of N_2O emissions associated
1288 with agricultural run-off from terrestrial sources that comes from either direct or indirect N application to
1289 terrestrial soils the inventory compiler is referred to Chapter 11 of the *2006 IPCC Guidelines*. The following
1290 assumption is applied under Tier 1 estimation: vegetation of coastal wetlands is not a source of non-CO_2 gases
1291 and the emission factor represents only fluxes directly from the soil to atmosphere.

1292 A second method for estimating indirect N_2O emissions from nutrient enrichment resulting from aquaculture
1293 effluent uses a modified form of Eq. 11.9 and 11.10 for effluent effects from aquaculture. The leaching factor
1294 can be applied and the EF from estuaries following this method. This method is recommended when absence of
1295 data on land area impacted by aquaculture effluent prevents use of that approach (see Chapter 11, Volume 4 of
1296 the *2006 IPCC Guidelines*).

TABLE 4.24 EMISSION FACTORS FOR CH_4 EMISSIONS FROM NUTRIENT ENRICHMENT (AGRICULTURAL RUN-OFF AND AQUACULTURE EFFLUENT) (TONNES CH_4 HA^{-1} YR^{-1})

Ecosystem	EF	95% CI	range	n
Mangrove forest and Tidal marsh (oligohaline - polyhaline)	1.13[1]	0.68, 1.18	0.015 – 27.83	18

[1] Mukhopadhyay et al. 2002, Kreuzwieser et al., 2003, Alongi et al., 2005, Biswas et al., 2007, Chauhan et al., 2008, Krithika et al., 2008, Liikanen et al., 2009, Allen et al., 2010, Chen et al., 2010, Tong et al., 2010, Adams et al., 2011.

1297

TABLE 4.25 EMISSIONS FACTORS FOR N_2O EMISSIONS FROM NUTRIENT ENRICHMENT (AQUACULTURE EFFLUENT) (KG N_2O HA^{-1} YR^{-1})

Ecosystem	EF	95% CI	range	n
Mangrove forest and Tidal marsh (oligohaline - polyhaline)	3.7[1]	0.19, 5.4	-4.6 – 66.3	17

[1] Corredor et al., 1999, Bauza et al., 2002, Kreuzwieser et al., 2003, Alongi et al., 2005,, Krithika et al., 2008, Liikanen et al., 2009, Chen et al., 2010, Adams et al., 2011, Allen et al., 2011, Chen et al., 2012.

1298

1299 *Tier 2 and 3*
1300 Tier 2 methods are used where countries have their country-specific emission factors and substantial national
1301 data. The Tier 2 method allows the inventory complier to adjust the assumptions applied to the Tier 1 method. It
1302 is a good practice to use the representative data of climate zones and vegetation type from published literature,
1303 e.g. papers, reports and books, and estimate the non-CO_2 gases emissions from wetland plants, where applicable.

1304 Tier 3 methods involve a comprehensive understanding and representation of the dynamics of non-CO_2 gas
1305 emission factors, taking account parameters such as salinity, season, N load, tidal elevation and tidal cycle (high
1306 tide vs. low tide). Field research should be carefully carried out at representative sites for empirical gas fluxes.
1307 Countries are encouraged to setup their own methodology or modelling exercises based on the N input rates for
1308 estimation of emission factors.

1309 ## 4.2.4.4   RESTORATION AND CREATION

1310 The degree of water saturation is a key factor controlling CH_4 and N_2O emissions. Rewetting of coastal wetland
1311 soils shifts microbial decomposition from aerobic to anaerobic conditions, increasing the potential for CH_4

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1312   emissions. If water used to rewet coastal wetlands increases N supplies through ground water or tidal water, a
1313   new source of N_2O emissions is possible.

1314   Guidance for inventories of rewetting and restoration or creation of coastal wetlands follows several general
1315   simplifying assumptions at Tier 1 level of estimation.

1316   (i)   The default assumption is that water introduced for rewetting, by whatever means, is ambient water
1317   free of excess nutrients.

1318   (ii)   Once rewetting occurs, the EF equals 0 for N_2O during a 20 year transition period is the default
1319   transition period unless the re-establishment of functioning vegetation is demonstrated to be
1320   unsuccessful.

1321   (iii) Once rewetting occurs, the EF for CH_4 in Table 4.27 should be applied during a 20 year transition
1322   period.

1323   (iv)   After the 20 year transition period which begins with the reestablishment of vegetation, the EF
1324   remains the same for both N_2O and CH_4 while the land continues to be subject to the management
1325   activity of restored or created, regardless of the land-use category that is applied.

1326   In the case of rewetting of lands that had been previously been in agricultural (or any other drained) land-use or
1327   category, for example, the prior land use is not considered at Tier 1 as any increase in emissions from rewetting
1328   has not only been shown to be a transient effect and data are insufficient to assign an EF to capture this effect.
1329   The water quality should be reevaluated to determine whether the EF for nutrient-enriched wetlands should
1330   continue to be applied. If water applied in the rewetting activity is enriched in nutrients and the restoration
1331   activity contributes to a land-use category or pool that is key, Tier 2 and 3 methods should be applied.

1332   **CHOICE OF METHOD AND EMISSION FACTORS**

1333   **Tier 1**

1334   *Mangrove and Tidal Marsh*
1335   The Tier 1 method in this section estimates the non-CO_2 emissions without considering the land use prior to
1336   rewetting. The Tier 1 default assumption is that the lands are rewetted with uncontaminated water. Thus, the
1337   emission factor for $N_2O = 0$ and for CH_4, emission factors are found in Table 4.26. For mangrove forests, the EF
1338   for CH_4 is zero. Default Tier 1 emission factors for rewetting and restoration or creation of coastal wetlands with
1339   organic and mineral soils are given in Table 4.21. These values should be used in conjunction with equation 4.2
1340   to estimate emissions and take into account the ambient soil salinity and vegetation type. For tidal marshes, the
1341 CH_4 EF is based on salinity (which is controlled by factors such as proximity to ocean water, the supply of
1342   freshwater through precipitation and fluvial inputs, and evapotranspiration).

TABLE 4.26 EMISSION FACTORS FOR CH_4 FROM UNMANAGED COASTAL WETLANDS FOR TIER 1 ESTIMATION OF REWETTING AND RESTORATION						
Wetland Type	Salinity type	Salinity (ppt)	Default EF (tonnes CH_4-C ha^{-1} y^{-1})	EF Range (tonnes CH_4-C ha^{-1} y^{-1})	Error (95%CI)	Reference
Tidal Marsh	Tidal fresh	0.5-5	1.12	0.03-4.04	±80%	Poffenbarger et al. 2011[1]
	Oligohaline/ Mesohaline	5-18	0.28	0.02-0.24		Poffenbarger et al. 2011[1]
	Polyhaline (>18ppt)	>18	0	0-0.04	±90%	Poffenbarger et al 2011[1]
Mangrove	Saline	>18	0		±90%	Page and Dal 2010
Note [1]Review paper						

1343

1344   **Tier 2 and Tier 3**

1345 Country-specific emission factors applied during the rewetting of the lands and the transition period should be
1346 used under Tier 2 methods, and the inventory compilers are encouraged to estimate the EF for the land during
1347 the transition to the new land category for the rewetted lands. Under the tier 3 method, the land use prior to
1348 rewetting, climate and vegetation type should be taken into account. A comprehensive understanding and
1349 representation of the dynamics of non-CO_2 gas emission factors, based on field measurement, is involved in Tier
1350 3. Tier 2 could include the use of country specific emission factors for each ecosystem that take into account
1351 local climatic factors, salinity, and species composition of the vegetation. The quality of the water should also be
1352 considered in the case of seagrass restoration.

1353 In the case of rewetting of lands that had been previously been in agricultural (or any other drained) land-use or
1354 category, for example, the prior land use is not considered at Tier 1 because data are insufficient to assign an EF
1355 to capture this transient effect. The emissions of N_2O and CH_4 are considered to also depend on the
1356 nutrient/organic matter available in the tidal water. The water quality should be reevaluated to determine whether
1357 the EF for nutrient-enriched wetlands should continue to be applied. If water applied in the rewetting activity is
1358 enriched in nutrients and the restoration activity contributes to a land-use category or pool that is key, Tier 2 and
1359 3 methods should be applied.

1360 Tier 2 and 3 should also consider the effect of vegetation as plants can act as conduit for gas exchange between
1361 the soil and atmosphere.

1362 ## 4.2.4.5   CHOICE OF ACTIVITY DATA

1363 ### Aquaculture ponds

1364 For aquaculture, this is the fish production, the amount of feed, and amount of N in feed. These data can be
1365 obtained from FAO (http://www.fao.org/fishery/statistics/global-aquaculture-production/en). To estimate non-
1366 CO_2 gas emissions from aquaculture activities, the area under cultivation must be determined either by on-site
1367 measurement or from aerial photographs. Also required is the rate of nitrogen input as feed, which can usually be
1368 obtained from the pond operator, and the sediment type beneath the cages or at the bottom of the pond. For
1369 additional guidance, see Section 4.2.1.3

1370 ### Nutrient enrichment

1371 To estimate CH_4 emissions, the area receiving agricultural runoff must be determined by visual inspection of the
1372 maximum ingress of tidal waters within the wetland. For Tier 2 and 3 methods, the rate of N input should be
1373 determined although this may be very difficult and may involve knowledge of the tidal prism and N
1374 concentrations in the waters in question. For nutrient enrichment, this is the area of nutrient--affected land. We
1375 can expect to find nutrient-affected systems downstream of major urban centers, municipal sewage treatment
1376 facilities, and watersheds where a large portion of the land is under intensive agricultural use. For additional
1377 guidance, see Section 4.2.1.3.

1378 ### Restoration/Creation

1379 To estimate non-CO_2 gas emissions, the area restored, created and/or rewetted must be determined by visual
1380 inspection of pre- and post-impact stages. The type of wetland and the salinity regime must be measured. For
1381 additional guidance, see Section 4.2.1.3.

1382 ## 4.2.4.6   UNCERTAINTY ASSESSMENT

1383 There have been few empirical measurements upon which to base emission factors and the factors identified for
1384 incorporation in Tier 2 and 3 will reflect variability. Uncertainties in non-CO_2 emissions associated with
1385 aquaculture can be reduced greatly by better estimation of fish production, quality of N in feed, area of ponds
1386 relative to total area under aquaculture use. For additional guidance, see Section 4.2.1.3.

1387 # 4.3   CONVERSION FROM A LAND USE CATEGORY
1388 # THAT INCLUDES COASTAL WETLANDS

1389 This section references methodology provided in Section 4.2 to estimate impacts of soil drainage, extraction or
1390 other activity when lands are classified under a land-use category other than Wetland. Examples of when
1391 classification of land into a different land-use category may occur are given in Box 4.1. In these cases, the

1392   inventory compiler is directed to the guidance in those chapters of Volume 4 of the *2006 IPCC Guidelines*
1393   (Chapter 5-Croplands, Chapter 8-Settlements) but applying the assumptions and default EFs provided here.

4.3.1 CO_2 emissions and removals

4.3.1.1   BIOMASS, DOM AND SOIL CARBON

1396   Permanent drainage under agriculture use or conversion to Settlements are cases in which a land-use conversion
1397   may be considered to have occurred. For biomass and DOM, see sections 4.2.1 and 4.2.2 unless land is
1398   converted to lands with dry soils in which case follow guidance in *2006 IPCC Guidelines* (following flow chart
1399   provided in Chapter 1). For soil carbon, refer to Chapter 2, this supplement for drained organic soils and the
1400   respective Chapters in the *2006 IPCC Guidelines* for land use conversion to lands with mineral soil. Regardless
1401   of how the land is classified, supplementary guidance provided in this Chapter should be followed where
1402   management activities where coastal wetlands are involved.

4.3.2   Non-CO_2 emissions

1404   This section provides guidelines for estimating non-CO_2 gas emissions from coastal wetlands, especially
1405   mangroves and tidal marshes being drained for conversion to other dry land uses. The land use following coastal
1406   wetland drainage (e.g., agriculture, settlement, forestry), will have a major impact on emissions of non-CO_2
1407   greenhouse gases from soils. Refer to the respective chapter depending on end Land Use in the *2006 IPCC*
1408   *Guidelines*. For guidance on drainage of organic soils and conversion to another IPCC Land-use category, refer
1409   to the guidance provided in Chapter 2, this supplement.

4.4   CONVERSION TO A LAND USE CATEGORY THAT INCLUDES COASTAL WETLANDS

4.4.1 CO_2 emissions and removals

1413   This section includes management activities that result in rewetting and restoration or creation of coastal wetland
1414   ecosystems and subsequent classification as Wetland. Land that is exposed to rewetting can previously have
1415   sustained mangroves or tidal marshes, but the previous land-use is characterised by (A) unsaturated soils due to
1416   sediment infill to a height above the water table, (B) drainage of the original ecosystem, (C) construction of
1417   dikes or levees that prevent tidal flooding, or (D) emplacement of culverts that restrict flow of tidal waters.

1418   Methods for biomass and DOM pools follow guidance provided in Sections 4.2.1 and 4.2.2. Non-CO_2 emissions
1419   are covered in section 4.4.4 and follow a similar approach with EFs for rewetting applied during the transitional
1420   land-use and EFs for restoration or creation applied when functioning vegetation has become re-established. For
1421   example, an aquaculture facility that is classified as Settlement or Cropland and restored to Wetlands would
1422   involve a change in IPCC land use category.

1423   Guidance for inventories of rewetting and restoration of coastal wetland ecosystems follows similar general
1424   simplifying assumptions at Tier 1 level of estimation of C emissions from soil (as presented in Section 4.2.3): 1)
1425   upon rewetting, EF=0 for a 20 year *transition* period (as opposed to *transient* period in the case of Land
1426   Remaining in a Land-use Category). The default transition period is 20 years unless the re-establishment of
1427   functioning vegetation is demonstrated to be unsuccessful, 2) after conversion to the new (restored or created
1428   coastal) land use category, a new EF is applied. The new EF is equivalent to the natural system net soil C
1429   accumulation (flux). Regardless of the land category, reestablishment of functioning vegetation is assumed to
1430   occur after a 20 year transition period (in the case of a land-use change to Wetlands) and a new EF is applied for
1431   soils (Table 4.21) following general guidance in Section 4.2.3.

4.4.2   Non-CO_2 emissions

1433   This section provides guidelines for estimating non-CO_2 gas emissions from coastal wetlands, especially
1434   mangroves and tidal marshes, undergoing management activities that result in rewetting and restoration or
1435   creation of coastal wetland ecosystems. These activities will have a major impact on emissions of non-CO_2
1436   greenhouse gases from soils. Apply methods and default EF provided in section 4.2.4.5.

1437 # 4.5   COMPLETENESS, TIMES SERIES
1438 #   CONSISTENCY, QUALITY ASSURANCE AND
1439 #   QUALITY CONTROL

1440 ## 4.5.1   Completeness

1441   Completeness is a requirement for greenhouse gas inventories, and it is *good practice* to address all wetland
1442   carbon gain and losses. For completeness, it is *good practice* to include all carbon pools and non-CO_2 gases. The
1443   wetland area used for calculation for different carbon pools must be the same, and emissions from organic and
1444   mineral soils on mineral soils should be estimated. Country-specific information should be incorporated into
1445   higher tier methodologies. A complete accounting of emissions and removals of CO_2 associated with for Land
1446   Remaining in a Land-use category, Land Converted to another Land-use category in which the land that is
1447   converted is a coastal wetland, and Conversion to a Land-Use category that includes coastal wetlands regardless
1448   of how it is classified. It is *good practice* that all losses from biomass carbon pools that result in transfers to dead
1449   organic matter pools are first accounted for as changes to biomass carbon stocks.

1450 ## 4.5.2   Developing a consistent time series

1451   It is good practice to develop a consistent time series of inventories of anthropogenic emissions and removals of
1452   greenhouse gases using the guidance in Chapter 7 in this volume. Achieving time series data may require
1453   extrapolation or interpolation from longer time series data or from long term trends, as few long-term data are
1454   available for most coastal wetlands.

1455   Consistent accounting over time of wetland areas included in biomass and soil C emissions and removals
1456   inventory requires that activity data be stratified by the common definitions of wetland type/ soil type. Wetlands
1457   subject to land-use change must not be lost or double-counted due to accounting errors resulting from
1458   inconsistent stratification of wetland types/ soil types. Ideally, the same protocol should be applied consistently
1459   every year in the time series, at the same level of disaggregation and where country-specific data are used, it is
1460   *good practice* to use the same values and methods for equivalent calculations throughout the time series.

1461   New values should be included if the inventory capacity and information and data sources improve over time. It
1462   is *good practice* in these circumstances to consistently recalculate the earlier emissions and removals. Other
1463   changes during the time series need to be consistent to take account of new data or methods and their consistency
1464   with the earlier data. It is *good practice* to recalculate the entire time series of data if the default values are
1465   changed; changes in wetland types need to be tracked for long periods of time.

1466   It is *good practice* to use the same model parameter values for the entire time series and to recalculate the entire
1467   dataset if one of more of the parameters has changed. Failure to do so may result in either under-or over-
1468   estimates of the true changes in carbon and non-CO_2 gas emissions or removals.

1469 ## 4.5.3   Quality assurance and quality control

1470   Different levels of precision and accuracy, and as a result, bias will invariably apply to a number of the values
1471   used to assess greenhouse gas inventories. Estimates are influenced by the quality and consistency of data and
1472   information available as well as knowledge gaps, all of which will vary among countries. Depending on the tier
1473   level used, estimates will be affected by different sources and degrees of error, such as sampling error.

1474   It is *good practice* to execute quality control checks through Quality Assurance (QA) and Quality Control (QC)
1475   procedures as detailed in Chapter 7, and review the emission estimation procedures by experts. Additional
1476   quality control checks as outlined in Chapter 7 and quality assurance procedures may also be applicable. This is
1477   especially so if higher tier methods are used. It is *good practice* to supplement the general QA/QC related to data

1478 processing, handling, and reporting and documenting, with source-specific procedures. QA/QC procedures
1479 should be documented separately for Land Remaining in a Land-use category, Land Converted to another Land-
1480 use category in which the land that is converted is a coastal wetland, and Conversion to a Land-Use category that
1481 includes coastal wetlands regardless of how it is classified.

1482 Organizations and institutions which collect the data are responsible for reviewing data collection methods and
1483 all aspects of the data handling and analysis procedures, and ensure that they are done correctly, and are
1484 complete and consistent over time. It is important to document all procedures and processes as it enables
1485 reviewers to identify inaccuracy, gaps and to suggest improvements. Transparency is most important in other to
1486 ensure consistency and clarity of the processes and procedures over time.

1487 All data should be checked against other reliable sources of information that are independent. Any differences or
1488 discrepancies must be documented, and consistency must be applied to total areas involved in the inventory to
1489 ensure that wetland area are neither 'created' or 'lost' overtime. When using country-specific data, the inventory
1490 compiler should compare these data to the IPCC default values or the Emissions Factor Database (EFDB) and
1491 detail any differences. These country-specific data must be of high quality, adequately described, and
1492 documented.

1493 If factors are based on direct measurements (i.e., soil C content) the inventory agency should review the
1494 measurements to ensure that they are representative of the actual range of environmental conditions. It is *good*
1495 *practice* to review and, if necessary, revise the default assumptions and to compare model estimates with field
1496 measurements and other data sources.

1497 4.5.4 Reporting and documentation

1498 General requirements for reporting and documentation are set out in Chapter 7. It is *good practice* to archive and
1499 document all data and information applied to produce the national emissions/removals inventory. Definitions of
1500 all carbon pools should be included in the inventory, including evidence that these definitions have been applied
1501 consistently over time.

1502 Documentation is necessary for demonstrating transparency, completeness, consistency of all data and methods
1503 for interpolating between samples, methods and years, and for recalculating and avoidance of possible double
1504 accounting or 'loss' of C inventory. Regardless of Tier methodology used, explanations are required for
1505 decisions regarding choice of methodology, approaches and use of default or other data. This is necessary to
1506 facilitate examination by independent third parties; inventories should include summaries of approaches and
1507 methods used and references to data sources so that the reported emissions estimates are transparent and can be
1508 retraced or recalculated.

1509 All data sources, including default values, must be quoted. The scientific basis for any country-specific data and
1510 methods must be completely described and justified, as well as describing sources and magnitudes of uncertainty.
1511 This is especially so for any large-scale estimates as in these cases the statistical procedures should be described
1512 and well as the level of uncertainty.

1513 Differences between years in emissions should be explained and the possible reasons for these differences
1514 documented as much as possible.

1515 4.6 FUTURE METHODOLOGICAL DEVELOPMENT

1516 4.6.1 C export

1517 The amount of dissolved and particulate carbon potentially available for export is highly variable among coastal
1518 wetlands, depending on a large number of factors such as: net primary productivity, tidal range, the ratio of
1519 wetland to watershed area, lateral trapping of tidal water, the presence of high salinity plugs in the tropical dry
1520 season, total wetland area, frequency of storms, amount of precipitation, and volume of water exchange Each
1521 ecosystem is unique; some wetlands export DOC but import POC, others import DOC and POC but export DIC,
1522 while other systems import or export all forms of dissolved and particulate carbon. The direction of net exchange
1523 also usually varies within the same estuary with change in season.

1524   Accurate estimation of tidal exchange in a particular wetland is not a straightforward process. Many workers
1525   have provided rough estimates by multiplying carbon concentrations suspended in wetland creeks and waterways
1526   by the tidal range multiplied by the creek/waterway cross-sectional area. Estimates derived from such simple
1527   calculations are invalid and misleading for a number of reasons, including the inherent assumption that there are
1528   differences in carbon concentrations between ebb and flood tide stages and that the tidal prism is symmetrical. In
1529   fact, carbon concentrations in many wetland waters do not show significant differences between tides. Further,
1530   tides in most wetlands are asymmetrical, characterized by a pronounced asymmetry between ebb and flood tides
1531   with the ebb most often being of shorter duration but with stronger current velocity than the flood tide. Also,
1532   tidal velocities vary across a waterway with faster surface current velocities mid-stream than those just above the
1533   creekbed or proximal to the wetland.

1534   For these reasons, it is not possible to make simple generalizations regarding total carbon export from mangroves,
1535   seagrasses or tidal marshes and, in fact, comparatively few such measurements have been made properly. The
1536   correct method would be to measure water volume and velocity over entire tidal cycles over several seasons in
1537   relation to position in the water-column to derive an overall annual estimate of average water flow by volume.
1538   This involves fairly complex instrument measurements and sophisticated mathematical modelling as well as
1539   extensive and expensive repetitive measurements of dissolved and particulate carbon concentrations. For
1540   mangroves, net exchange of carbon has been properly measured in only twelve systems, with no clear exchange
1541   patterns among locations, although it does appear that most mangroves export POC as litter but with rates
1542   ranging widely from 0.1-27.7mol C m^{-2}yr^{-1}(Alongi, 2009). This export equates globally to only about 10% of
1543   total carbon fixed by trees; respiration to the atmosphere is by far the largest loss of C to the atmosphere. Such
1544   appears to be the case for tidal marshes (Chmura et al., 1993) and subtidal seagrass beds (Fourqurean et al., 2012)

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ANNEX 4.1 PERCENT REFRACTORY CARBON

2517 Percent refractory carbon in organic/mineral soils were estimated for mangrove soils based on either the amount
2518 of phenolic compounds/lignins in soils or % TOC in mangrove soils deeper than 1 m if there was no further
2519 decline in TOC concentration (Table 4.3).

PERCENT REFRACTORY CARBON APPLIED TO ESTIMATE % C OXIDATION FOR MANGROVE SOILS (% BY SOIL DRY WEIGHT)	
Mean	3.98
Median	3.4
N	16
Prasad & Ramanathan 2009; Marchand et al. 2003;Dittmar & Lara 2001; Koch et al.2011; Ranjan et al.,2010; Marchand et al. 2005), which is similar to that in tidal marshes (Filip et al. 1988; Alberts et al., 1988; Ramesh et al. 2008)	

2527

2528

ANNEX 4.2 ADDITIONAL SOURCES FOR ACTIVITY DATA

2530 The following web sources provide links to domestic and international data sources pertaining to coastal wetland
2531 areas and other activity data for management activities contained in this chapter. Other web sources are provided
2532 in the text of the chapter in the respective activity data sections. Resources providing recent trends in coastal
2533 wetland area can help countries understand circumstances of those trends and what management activities
2534 contribute   to   them   (FAO   2007;   Green   and   Short   2003
2535 http://archive.org/stream/worldatlasofseag03gree#page/n5/mode/2up;   Sifleet   et   al.   2011,
2536 http://nicholasinstitute.duke.edu/publications/; Fatoyinbo & Simard 2013)

Mangroves

2538 Mangrove.org: http://mangrove.org/

2539 Mangrove Action Project: http://www.mangroveactionproject.org/

2540 Mangrove, National Geographic Magazine: http://ngm.nationalgeographic.com/2007/02/mangroves/warne-text

2541 FAO Mangrove Management: http://www.fao.org/forestry/mangrove/en/

2542 USGS National Wetlands Research Center: http://www.nwrc.usgs.gov/index.html

2543 World Atlas of Mangrove: http://www.fao.org/forestry/20067/en/

ED_005856B_00001951-00066

2544   World   Distribution   of   Coral   Reefs   and   Mangroves: http://www.unep-
2545   wcmc.org/marine/data/coral_mangrove/marine.maps.main.html

2546   International Society for Mangrove Ecosystems: http://www.mangrove.or.jp/

2547   Global Mangrove Database & Information System: http://www.glomis.com/

2548   The UNESCO Mangrove Programme: http://www.unesco.org/csi/intro/mangrove.htm

2549   Mangrove and the Ramsar Convention: http://www.ramsar.org/types_mangroves.htm

2550   USGS Global Mangrove Project http://lca.usgs.gov/lca/globalmangrove/index.php

2551   **Mangroves, tidal marshes and seagrass meadows**

2552   http://data.unep-wcmc.org/

2553   Global distribution of seagrasses (V2.0, 2005) prepared by UNEP World Conservation Monitoring Centre
2554   (UNEP-WCMC) in collaboration with Dr. Frederick T. Short.

2555   Global distribution of Mangroves (V3.0, 1997) compiled by UNEP World Conservation Monitoring Centre
2556   (UNEP-WCMC) in collaboration with the International Society for Mangrove Ecosystems (ISME).

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2559   **ANNEX 4.3 ACCURATE ESTIMATION OF ABOVEGROUND MANGROVE**
2560   **BIOMASS: HIGHER TIER METHODOLOGY**

2561   Because of field conditions and heavy weight of wood, an accurate survey of a mangrove forest is difficult and
2562   time-consuming. Allometric methods (Soares and Schaeffer-Novelli, 2005; Komiyama et al., 2008) estimate the
2563   whole or partial weight of a tree from measurable tree dimensions, notably trunk diameter and height, using
2564   allometric relations developed from empirical measurement of weight of individual tree components (leaves,
2565   branches, stem). Use of allometric equations is favored because it is non-destructive and is therefore useful for
2566   estimating temporal changes in forest biomass by means of subsequent stem diameter measurements over
2567   subsequent years.

2568   Up until recently, the major drawback of this method has been the site- and species-specific differences in
2569   allometric relations, necessitating the use of different allometric equations for different sites (e.g., Smith and
2570   Whelan, 2005) and, at a minimum, different species. However, a number of workers, using global datasets, have
2571   developed a common allometric equation applicable for all tropical tree species, with the most applicable
2572   equations for aboveground biomass being those developed for all tropical trees by Chave et al. (2005) and for all
2573   mangrove species by Komiyama et al. (2005):

$$W_{top} = 0.168p\mathrm{DBH}^{2.47} \text{ (Chave et al. 2005)}$$

$$W_{top} = 0.251p\mathrm{D}^{2.46} \text{ (Komiyama et al. 2005)}$$

2576   where W_{top} = aboveground tree weight in kg DW; D = tree diameter; DBH = diameter-at-breast height. The
2577   relative error of each equation varies among species, but is typically within the range of -10% to +10%. There
2578   are, of course, arguments to be made that empirical measurements should be made in all mangrove forests,
2579   considering the significant allometric differences between species and for the same species at different locations
2580   (Smith and Whelan, 2005; Soares and Schaeffler-Novelli, 2005). However, this idea is impractical for inventory
2581   compliers; a relative error of ± 10% is acceptable being within the range of error for allometric relations within a
2582   forest where biomass has been weighted.

2583   Comparing the two equations, the Chave estimation gives lower aboveground weight estimates than that of the
2584   Komiyama equation. Presuming that a complete census of all trees, with species identified, and their diameter
2585   have been undertaken from replicate plots within a given forest, these numbers can then be used in either
2586   equation to derive individual tree weight.